West

Major civil construction between The Bays and Sydney CBD

Environmental Impact Statement 2021

Technical Paper 7

Hydrogeology

Project:	Sydney Metro West
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Executive summary

Sydney Metro, Australia's biggest public transport program, is aiming to deliver an integrated transport system that meets the needs of customers now and those in the future, with its delivery critical to keep Sydney moving. The Sydney metro program includes the Metro North West Line (which opened in May 2019), Sydney Metro City & Southwest (which is currently under construction and due to open in 2024), Sydney Metro West (this proposal) and Sydney Metro Western Sydney Airport (which is currently in the final stages of planning).

The planning process for Sydney Metro West is being assessed as a staged infrastructure application under section 5.20 of the *Environment Planning and Assessment Act 1979* (EP&A Act).

The Sydney Metro West Concept and major civil construction work for Sydney Metro West between Westmead and The Bays (Stage 1 of the planning approval process for Sydney Metro West), application number SSI-10038, were approved on 11 March 2021.

The Concept includes:

- Construction and operation of new passenger rail infrastructure between Westmead and the central business district of Sydney, including:
  - Tunnels, stations (including surrounding areas) and associated rail facilities
  - Stabling and maintenance facilities (including associated underground and overground connections to tunnels)
- Modification of existing rail infrastructure (including stations and surrounding areas)
- Ancillary development.

Major civil construction work for Sydney Metro West between Westmead and The Bays includes:

- Tunnel excavation including tunnel support activities between Westmead and The Bays
- Station excavation for new metro stations at Westmead, Parramatta, Sydney Olympic Park, North Strathfield, Burwood North, Five Dock and The Bays
- Shaft excavation for services facilities
- Civil work for the stabling and maintenance facility at Clyde.

Stage 2 (this proposal) of the planning approval process includes all major civil construction work including station excavation and tunnelling between The Bays and Sydney CBD. Key features of this proposal include:

- Enabling works such as demolition, utility supply to construction sites, utility adjustments, and modifications to the existing transport network
- Tunnel excavation including tunnel support activities
- Station excavation for new metro stations at Pyrmont and the Sydney CBD.

This proposal includes all major civil construction work including station excavation and tunnelling between The Bays and Hunter Street Station (Sydney CBD).

Future planning applications for Sydney Metro West will include tunnel fit-out, station building fit-out and operation of the line between Westmead and Hunter Street Station (Sydney CBD).

The groundwater impact assessment

This technical paper has been prepared to support the Environmental Impact Statement (EIS) by identifying and assessing the potential cumulative impacts of the Proposal during construction, in relation to groundwater. In doing so, this technical paper responds directly to the Secretary's Environmental Assessment Requirements (SEARs).

The SEARs issued by the NSW Department of Planning, Industry and Environment (DPIE) requires a groundwater impact assessment to support the EIS being prepared for the Proposal. This technical paper was carried out through the review of background information, site investigation data, and simulated predictions of groundwater flow.

The predictions comprised water level drawdown and seawater intrusion assessment with water inflow predictions of the proposed construction using a three-dimensional numerical model.

Simulated groundwater drawdown contours were determined based on the Sydney Metro Design Submission Constructability Report dated 19 February 2021, regional hydrogeological data, and local geotechnical and hydrogeological data collected. For assessment of potential cumulative impacts associated with the proposal, the following simulations have been undertaken:

- The pre-construction water table contours presented in this technical paper are conservative estimates to take into account the numerous buildings with deep basements, which calibrate well with the urbanised built environment.

- Construction phase drawdown contours and inflows were estimated at 6 months, 1 year, and 2 years intervals from commencement of the station caverns construction.

Assessment methodology

Through a review of relevant groundwater information, monitoring data and in situ tests of hydraulic properties, an understanding of the existing hydrogeology has been developed. Appropriate simulations methods were used to predict potential changes in groundwater levels and flow that may be caused through the construction. The findings were used to identify potential impacts due to the Pyrmont and Hunter Street Stations as well as the impacts of running tunnels and cross over caverns. The cumulative groundwater impacts of these developments were also identified.

A discussion of compliance in relation to licencing, the NSW Aquifer Interference Policy and Water Sharing plan was prepared and recommendations to achieve groundwater compliance were developed. The recommendations included a discussion of a groundwater management approach, mitigation measures and monitoring requirements.

Existing conditions

The proposal footprint lies on the southern side of the Sydney Harbour extending from the Bays Station to the centre of the Sydney CBD (Hunter street). Key features along the shoreline include White Bay, Johnstons Bay, Pyrmont Bay, Blackwattle Bay, Cockle Bay and Sydney Cove. The topography is gently underlying and drains towards the harbour. Most of the drainage canals are lined. The surface is densely urbanised, covered by paved areas and high-rise buildings, interspersed with a few recreation parks and gardens. The underlying geology comprises predominantly of Triassic Hawkesbury Sandstone overlain by Ashfield Shale. The surface soils are largely anthropogenic (man-made) fill. Alluvial sands are found along low lying drainage lines. Acid sulfate soils exist along the shores of the harbour. A few faults and igneous intrusions trend in a northerly direction, the most notable being the Great

Sydney Dyke which is just east of the Bays Station. Ground water recharge is from a combination of rainfall, seepage losses from drainage channels and leaking pipes. Groundwater flow directions are mostly northerly towards the harbour. The flow paths also reflect a subdued, near surface piezometric topography similar to that of the surface topography which drains towards the numerous bays along the edge of the harbour.

Potential construction impact

Potential impacts were assessed by reviewing the predicted groundwater level drawdown due to this proposal in relation to conditions of existing supply bores; groundwater dependent ecosystems; acid sulfate soils; and existing groundwater recharge, flow and surface water-groundwater behaviour.

The results for Pyrmont showed that a total of 26 megalitres of water would drain into the excavated cavern and shafts in the first year of the excavation process and 15 megalitres in the second year. The drainage would create a drawdown cone that is predicted to extend to the edge of Cockle Bay which is only about 250 away from the eastern shaft. The development of a saline/freshwater interface was identified and predicted to start migrating towards the easter shaft. The underlying saline water located beneath the shaft would also rise. This process would commence during the construction stage. Estimates indicated that it could take between six and ten years for saline water to migrate from Cockle Bay to the Eastern Shaft of Pyrmont Station.

Similarly, the model results for Hunter Street Station showed that a total of 35 megalitres of water would drain into the excavated cavern and shafts in the first year of the excavation process and a further 18 megalitres in the second year. The drainage would create a drawdown that is predicted to extend to the edge of the Sydney Harbour in the vicinity of the Cahill Expressway by the end of the construction period. The drawdown may initiate some saline intrusion at the edge of the harbour, but the station is about 550m away for the harbour and less likely to be impacted upon by an intrusion of salt water. Modelling of the saline/freshwater interface was not conducted for the Hunter Street Station but such modelling should be considered in subsequent project Stages.

The risk of cumulative impacts in the Pyrmont and the Hunter Street Station (Sydney CBD) area is considered medium to high. These areas are already highly altered by numerous tunnels, basements and barriers, and the construction dewatering is likely to add to the overall existing drawdown.

The estimated groundwater drawdowns are considered conservative as pre-existing drawdown has not been accounted for. A conservative (worst case) simulation was purposefully conducted to ensure that impacts could be identified. Further assessment would be necessary to include the influence of the pre-existing drawdown.

An examination of the simulated results in relation to existing maps and information regarding items of environmental and water use significance showed that there are no potential groundwater dependent ecosystems in proximity to the alignment and areas affected by groundwater drawdown.

With respect to beneficial water users, each has a unique set of water quality criteria designed to protect the environmental value of the groundwater resource. For purposes of this assessment, the ‘environmental values’ pertaining to aquatic ecosystems, primary industries, industrial water, and cultural values were considered to ascertain whether they were potentially applicable. It was found that ‘Environmental values’ pertaining to drinking water are not applicable as the groundwater quality is generally not suitable for drinking water due to poor groundwater quality.

The majority of creeks that this proposal passes beneath at depth, which may be fed by groundwater baseflow at times, have been identified as having visual amenity values. A few have also been identified as having primary or secondary contact recreation (e.g., White Bay).

Cultural values are not considered applicable as groundwater-related Aboriginal cultural heritage sites have not been identified in the vicinity of this proposal. There are no high priority culturally significant sites listed in the schedule of the Water Sharing Plan.

Potential cumulative impacts on Aquatic Ecosystems will be minimised by incorporating the management of groundwater discharged from subsurface shafts and station caverns, into the Sydney Metro's Construction Environmental Framework (discussed below).

The total inflow is predicted to be up to 38.5 megalitres in the first six months, up to 61.3 megalitres in the remainder of the first year, and up to 33.2 megalitres in the second year (total of 94.5 megalitres over both years).

There is currently about 44,000 megalitres per year that is unassigned under the long-term average annual extraction limit under the Water Sharing Plan for the Sydney Basin Central Groundwater Source. Annual inflows would be less than one per cent of the unassigned water. This proposal is therefore not likely to impact the unassigned water available under the Water Sharing Plan.

Proposed management and mitigation measure

Management and mitigation measures have been proposed for the construction phase of this proposal and documented in Sydney Metro's Construction Environmental Management Framework.

These measures along with those recommended in Technical Paper 7, Technical Paper 8 and Technical Paper 10 will address the Secretary's Environmental Assessment Requirements associated with hydrogeological impacts by this Proposal.

TERMINOLOGY

Term	Definition
AEI	Area of Environmental Interest
AIP	NSW Aquifer Interference Policy
BOM	Bureau of Meteorology
BTEX	Benzene, toluene, ethylbenzene, xylenes
DPI	Department of Primary Industries
GDE	Groundwater dependent ecosystem
LTAAEL	Long-term average annual (groundwater) extraction limit
NEPM	National Environment Protection (Assessment of Site Contamination) Measure 1999
NWQMS	National Water Quality Management Strategy
OCP	Organochlorine pesticides
OPP	Organophosphate pesticides
PAH	Polycyclic aromatic hydrocarbons
SEARs	Secretary’s environmental assessment requirements
Tanked	The sides, floor and ceiling of the sub-surface excavation are sealed to minimise the ingress of water.
TRH	Total recoverable hydrocarbons
Untanked	The sides, floor and/or ceiling of a sub-surface excavation have not been sealed, enabling seepage to enter the excavation
VWP	Vibrating Wire Piezometers
VOC	Volatile Organic Compounds

1 Introduction

1.1 Sydney Metro West

Sydney Metro West will double rail capacity between Greater Parramatta and the Sydney CBD, transforming Sydney for generations to come.

The once-in-a-century infrastructure investment will have a target travel time of about 20 minutes between Parramatta and the Sydney CBD, link new communities to rail services and support employment growth and housing supply.

Stations have been confirmed at Westmead, Parramatta, Sydney Olympic Park, North Strathfield, Burwood North, Five Dock, The Bays, Pyrmont and Hunter Street (Sydney CBD). The main elements of Sydney Metro West are shown in Figure 1-1.

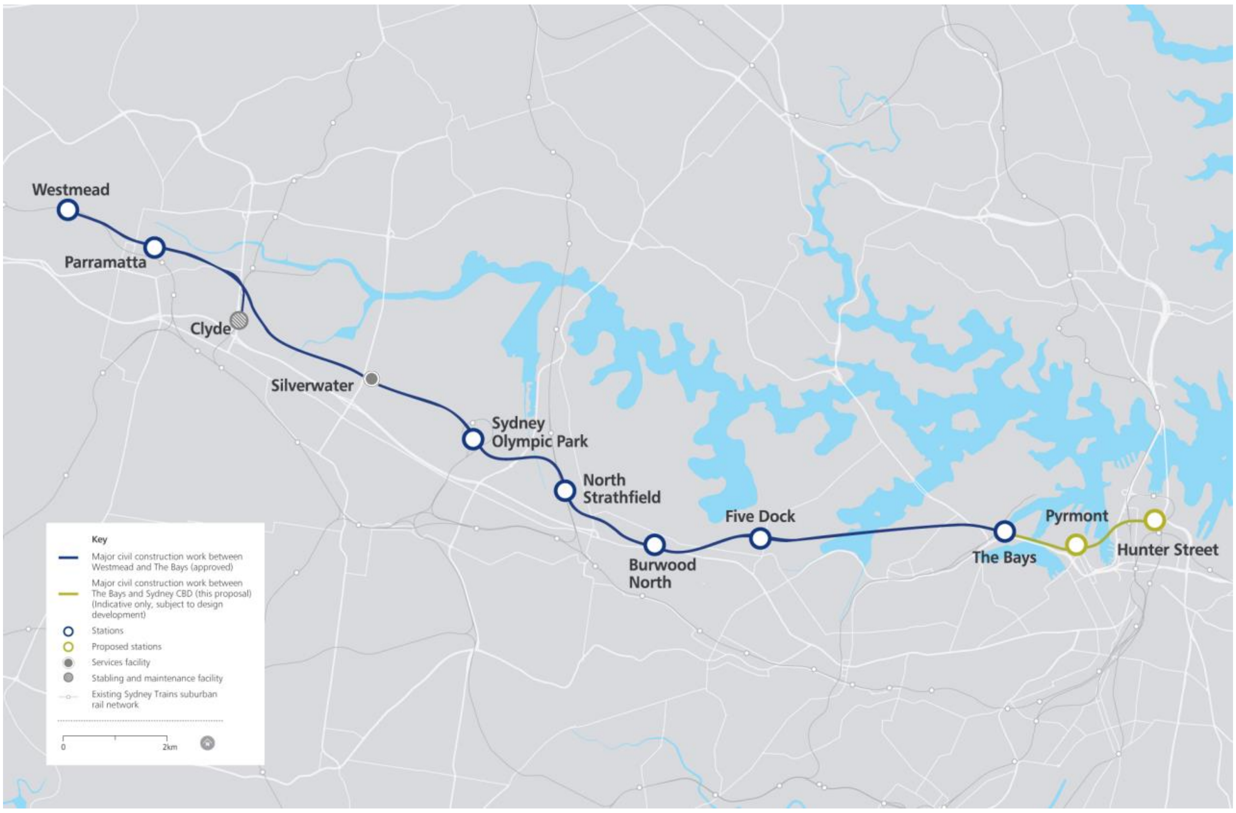

Figure 1-1: Sydney Metro West

The planning process for Sydney Metro West is being assessed as a staged infrastructure application under section 5.20 of the *Environment Planning and Assessment Act 1979* (EP&A Act).

The Sydney Metro West Concept and major civil construction work for Sydney Metro West between Westmead and The Bays (Stage 1 of the planning approval process for Sydney Metro West), application number SSI-10038, were approved on 11 March 2021.

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- Construction and operation of new passenger rail infrastructure between Westmead and the central business district of Sydney, including:
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Major civil construction work for Sydney Metro West between Westmead and The Bays (Stage 1 of the planning approval process) includes:

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- Shaft excavation for services facilities
- Civil work for the stabling and maintenance facility at Clyde.

Stage 2 of the planning approval process (this proposal) includes all major civil construction work including station excavation and tunnelling between The Bays and Sydney CBD.

Future planning applications for Sydney Metro West will include tunnel fit-out, station building and fit-out and operation of the line between Westmead and Sydney CBD.

1.2 Overview of the proposal

This proposal would include three main station sites connected underground by twin tunnels. The sites are within relative proximity to various bays of the inner Sydney Harbour. Indicative locations of the proposed alignment and stations are shown in Figure 1-2.

Figure 1-2: Overview of Sydney Metro West between The Bays and Sydney CBD

The proposed major civil construction work between The Bays and Sydney CBD would include:

- Enabling work such as demolition, utility supply to construction sites, utility adjustments, and modifications to the existing transport network
- Tunnel excavation including tunnel support activities
- Station excavation for new metro stations at Pyrmont and at Hunter Street, in the Sydney CBD.

Components of this proposal are subject to further design, and changes may be made during the ongoing design which take into account the outcomes of community and stakeholder engagement and environmental field investigations.

The surface construction work at station and shaft excavation sites are temporary, with the construction proposed in the proposal intended to occur across a period of about three years. This includes one year for surface works pre and post excavation and two years for excavations. Groundwater related construction impacts are assumed to cover a period of two years. A two year period was therefore adopted for the analyses presented in this technical paper.

The proposal is further described in Chapter 5 (Proposal description) of the Environmental Impact Statement.

It is important to note that The Bays tunnel launch and support site has been approved as part of the *Sydney Metro West Environmental Impact Statement – Westmead to The Bays and Sydney CBD* (Sydney Metro, 2020a). This included the use of the site to:

- Carry out the excavation of The Bays tunnel launch and support site

- Launch and support the tunnel boring machine for the drive west to the Sydney Olympic Park metro station construction site.

The Bays tunnel launch and support site is being established under the Concept and Stage 1 planning approval process for Sydney Metro West.

This Technical Paper only assesses the proposed eastern and southern part of The Bays tunnel launch and support site, which is intended to support two tunnel boring machines, working eastwards from the drive, to the proposed Hunter Street Station (Sydney CBD) construction sites. There would be minimal additional surface ground disturbance associated with groundwater draw down resulting from this work, but groundwater impacts will be considered.

1.3 Purpose and scope of this Technical Paper

This Hydrogeology Technical Paper 7 is one of a number of technical papers that form part of the Environmental Impact Statement for major civil construction work between The Bays and Sydney CBD. The purpose of this Technical Paper is to identify and assess the potential impacts of the proposal in relation to Hydrogeology. It responds directly to the Secretary's Environmental Assessment Requirements (SEARs) outlined in Section 1.4.

The objectives of this Technical Paper include:

- Construction Stage impacts on groundwater hydrology (including drawdown, flow rates and volumes) are minimised
- Assessment of the potential impacts
- Assessment of cumulative impacts (if relevant)
- Identification of measures to mitigate and manage the identified impacts.

1.4 Secretary's Environmental Assessment Requirements

The SEARs were issued on 7 July 2021. The response to the SEARS for groundwater is split across Technical Paper 7 (Hydrogeology) and Technical Paper 9 (Hydrology, Flooding and Water Quality). This Technical Paper has been prepared in line with the SEARS specific to Hydrogeology, and where these requirements are assessed in this Technical Paper, are outlined in Table 1-1.

In support of seeking the SEARs, the Sydney Metro West Scoping Report – Major civil construction from The Bays to Sydney CBD (Sydney Metro, 2021) identified a number of investigations and further assessments relevant to this Technical Paper.

Table 1-1: Secretary's Environmental Assessment Requirements – Hydrology

Secretary's environmental assessment requirements	Where addressed
Water – Hydrology	
1. Describe (and map) the existing hydrological regime for any surface and groundwater resource (including reliance by users and for ecological purposes) likely to be impacted by the proposal, including stream orders, as per the Framework for Biodiversity Assessment (FBA).	Section 4 and Technical Paper 9 – Hydrology, Flooding and Water Quality

Secretary's environmental assessment requirements	Where addressed
2. Provide a water balance for ground and surface water including the proposed intake and discharge locations, volume, frequency and duration.	Section 5.12, and section 5.3 of Technical Paper 9 – Hydrology, Flooding and Water Quality
3. Surface and groundwater hydrology impacts of the proposal in accordance with the current guidelines, including: (a) impacts from any permanent and temporary interruption of groundwater flow, including the extent of drawdown, barriers to flows, implications for groundwater dependent surface flows, groundwater users and the potential for settlement; and	Section 5.13
(b) minimising the effects of proposed stormwater and wastewater management during construction on natural hydrological attributes (such as volumes, flow rates, management methods and re-use options) and on the conveyance capacity of existing stormwater systems where discharges are proposed through such systems.	Section 5, and section 5.1 of Technical Paper 9 Hydrology, Flooding and Water Quality
4. Identify any requirements for baseline monitoring of hydrological attributes.	Section 5.13
Water – quality	
1. Surface and groundwater quality impacts including:	
(a) identifying and estimating the discharge water quality and degree of impact that any discharge(s) may have on the receiving environment, including consideration of all pollutants that pose a risk of non-trivial harm to human health and the environment;	Section 4.7, and section 5.2 of Technical Paper 9 – Hydrology, Flooding and Water Quality Technical Paper.
(b) identifying the rainfall event that the water quality protection measures will be designed to cope with; and	Table 6-2 of Technical Paper 9 – Hydrology, Flooding and Water Quality Technical Paper
(c) assessing the significance of any identified impacts including consideration of the relevant ambient water quality outcomes	Section 5, and section 5.2.3 of Technical Paper 9 – Hydrology, Flooding and Water Quality Technical Paper
2. Demonstrating how this proposal will, to the extent that the proposal can influence, ensure that:	Section 4.8 and 6.3 of Technical Paper 9 – Hydrology, Flooding and Water Quality
(a) where the NSW Water Quality Objectives (WQOs) for receiving waters are currently being met they will continue to be protected; (b) where the NSW WQOs are not currently being met, activities will work toward their achievement over time; and	

Secretary’s environmental assessment requirements	Where addressed
(c) justify, if required, why the WQOs cannot be maintained or achieved over time.	
Contamination	
Commitments made in Section 9.9.2 of the Scoping Report	Table 1-2 of Technical Paper 8 – Contamination
The risk of contamination and identify if remediation of the land is required, having regard to the ecological and human health risks posed by the contamination in the context of past, existing and future land uses. Where assessment and/or remediation is required, the Proponent must document how the assessment and/or remediation would be carried out in accordance with current guidelines.	Section 3.8, section 3.9, section 4 and section 7 of Technical Paper 8 – Contamination.

Table 1-2: Proposed investigations and assessments for groundwater, as identified in Sydney Metro West Scoping Report – Westmead to The Bays and Sydney CBD

Proposed investigations and assessment	Where addressed
Describe the aquifer system(s) traversed by Stage 1	Section 4.9
Identify existing groundwater levels along the alignment and near the stations and portals	Section 4.6.1 and section 5.7.1
Identify sensitive groundwater receivers (registered groundwater bores)	Section 4.6.2
Discuss the nature and extent of potential impacts on groundwater associated with construction and the ongoing presence of infrastructure including tunnels and station excavations. Seepage analysis and expected drawdown and its impact on built environment. This would consider existing groundwater levels, the geological context and ground permeability and seepage, the extent to which the infrastructure is ‘tanked’ (designed to inhibit the inflow of groundwater) and experience on other projects (including groundwater inflow rates)	Section 5.6, section 5.7 and section 5.8
Identify potential impacts on groundwater quality	Section 5.7.4, and 5.8.4 of Technical Paper 8 – Contamination
Propose monitoring/management measures to address identified impacts	Section 7 of Technical Paper 8 – Contamination

1.5 Structure of this Technical Paper

The structure of this Technical Paper is outlined below:

- Chapter 1 (this chapter) outlines an introduction to the proposal
- Chapter 2 presents relevant legislative and policy context to this proposal
- Chapter 3 documents the assessment methodology for this assessment

- Chapter 4 details the existing hydrogeological environment
- Chapter 5 provides an assessment of the potential hydrogeology impacts of this proposal during construction, including cumulative impacts
- Chapter 6 identifies mitigation and management measures.

2 Legislative and policy context

This section presents relevant regulation, legislation and policy governing management of groundwater and groundwater quality as it pertains to this proposal.

2.1 Commonwealth legislation

2.1.1 Commonwealth Environment Protection and Biodiversity Conservation Act

The *Commonwealth Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act) prescribes the Commonwealth Government's role in environmental assessment, biodiversity conservation and the management of protected areas and species, population and communities and heritage items.

Approval from the Commonwealth Minister for the Environment is required for:

- An action which has, would have, or is likely to have a significant impact on 'matters of National Environmental Significance' (MNES). The MNES of most relevance to the groundwater assessment are the Ramsar wetlands of international importance
- An action by the Commonwealth or a Commonwealth agency which has, would have, or is likely to have a significant impact on the environment
- An action on Commonwealth land which has, would have, or is likely to have a significant impact on the environment
- An action which has, would have, or is likely to have a significant impact on the environment of Commonwealth land, no matter where it is to be carried out
- Impacts on groundwater due to this proposal may be relevant under the *EPBC* Act where groundwater is shown to support MNES, such as wetlands or ecological communities.

2.2 National policy

2.2.1 National Water Quality Management Strategy

The National Water Quality Management Strategy (NWQMS) is the adopted national approach to protecting and improving water quality in Australia. It consists of a number of guideline documents, with specific documents relating to the protection of surface water and groundwater resources.

The primary document relevant to the assessment of groundwater risks for this proposal is the *Guidelines for Groundwater Quality Protection in Australia* (Australian Government, 2013). This document sets out a high-level risk-based approach to protecting or improving groundwater quality for a range of groundwater beneficial uses (called 'environmental values'). The beneficial uses are as follows:

- Aquatic ecosystems, comprising the animals, plants and micro-organisms that live in water, and the physical and chemical environment and climatic conditions with which they interact
- Primary industries, including irrigation and general water users, stock drinking water, aquaculture and human consumption of aquatic foods
- Recreation and aesthetic values, including recreational activities such as swimming and boating, and the aesthetic appeal of water bodies

- Drinking water, which is required to be safe to use and aesthetically pleasing
- Industrial water, such as water used for industrial processes including cooling towers, process water or wash water
- Cultural and spiritual values, which may relate to a range of uses and issues of a water source, particularly for indigenous people, including spiritual relationships, sacred sites, customary use, the plants and animals associated with water, drinking water or recreational activities.

Each beneficial use has a unique set of water quality criteria designed to protect the environmental value of the groundwater resource. For the purposes of this assessment, 'environmental values' pertaining to aquatic ecosystems, primary industries, industrial water, and cultural values are considered potentially applicable. 'Environmental values' pertaining to drinking water are not applicable as the groundwater quality is generally not suitable for drinking water due to poor groundwater quality. The majority of creeks that this proposal passes beneath at depth, which may be fed by groundwater baseflow at times, have been identified as having visual amenity values. A few have also been identified as having primary or secondary contact recreation (e.g. White Bay).

Cultural values are not considered applicable as groundwater-related Aboriginal cultural heritage sites have not been identified in the vicinity of this proposal. There are no high priority culturally significant sites listed in the schedule of the Water Sharing Plan.

The Australian and New Zealand Governments and Australian state and territory governments are part of the NWQMS. Refer to Technical Paper 7 (Jacobs, 2020a) of the Environmental Impact Statement for more information.

2.2.2 Australian Groundwater Modelling Guidelines

The Australian Groundwater Modelling Guidelines 2012 provide a point of reference and a consistent approach to groundwater flow and solute transport models in Australia. They also detail the approach to model the interaction between surface water and groundwater bodies. Further discussion of these guidelines is included in Technical Paper 8 (Jacobs, 2020a) of the Environmental Impact Statement.

2.3 NSW legislation

2.3.1 Water Act 1912, Water Management Act 2000 and Water Management Regulation 2018

Water resources in NSW are administered under the *Water Act 1912* and the *Water Management Act 2000* by the NSW Department of Planning, Industry and Environment. The *Water Management Act* 2000 governs the issue of water access licences and approvals for those water sources (rivers, lakes, estuaries and groundwater) in NSW with a Water Sharing Plan. The region is bounded by the Hawkesbury River catchment to the north and west and the Shoalhaven River catchment to the south and south-west. The region also includes the groundwater of the Illawarra and metropolitan Sydney.

In accordance with Section 5.23(1) of the EP&A Act, the following approvals, which may have otherwise been required to undertake this proposal, would not be required for approved State significant infrastructure:

- Water use approval under Section 89 of the *Water Management Act 2000*
- Water management work approval (including a water supply works approval) under section 90 of the *Water Management Act*

- Activity approval under Section 91 of the *Water Management Act 2000*.

2.3.2 Protection of the Environment Operations Act 1997

Section 120 of the *Protection of the Environment Operations Act 1997* (POEO Act) prohibits the pollution of waters by any person. Under section 122, holding an environment protection licence is a defence against accidental pollution of watercourses.

2.3.3 Water sharing plans

Water sharing plans, following the introduction of the *Water Management Act 2000*, provide the basis for equitable sharing of surface water and groundwater between water users, including the environment.

The majority of NSW is now covered by Water Sharing Plans including this proposal. Therefore, the *Water Act 1912* is not relevant. If an activity leads to a take from a groundwater or surface water source covered by a Water Sharing Plan, then an approval and / or license is required. In general, the *Water Management Act 2000* requires:

- A water access licence to take water
- A water supply works approval to construct a work
- A water use approval to use the water.

This proposal lies within the Sydney Basin Central Groundwater Source. The Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011 (the Water Sharing Plan) applies to the Sydney Basin Central Groundwater Source.

The Water Sharing Plan contains provisions for allocation of water to construction projects through a volume of 'unassigned water' or through the ability to purchase an entitlement where groundwater is available under the long-term average annual extraction limit (LTAAEL).

The LTAAEL for the Sydney Basin Central is 45,915 megalitres per year, which is 25 per cent of the estimated annual recharge for the area. Under the Water Sharing Plan, there are currently 120 groundwater access licences, with a total licensed volume of 2,592 megalitres per year. As such there is up to 43,323 megalitres per year of water currently available under the LTAAEL.

The Sydney Basin Central Groundwater Source is declared a Less Productive Groundwater Source by the NSW Office of Water (now WaterNSW). Therefore, Less Productive Minimal Impact Considerations of the NSW Aquifer Interference Policy apply with respect to Porous and Fractured Rock Water Sources.

2.4 NSW policy

2.4.1 NSW Aquifer Interference Policy

The NSW Aquifer Interference Policy (AIP) (Office of Water, 2012) is a component of the NSW Strategic Regional Land Use Policy and was introduced in September 2012. The AIP defines the regime for protecting and managing impacts of aquifer interference activities on NSW's water resources and strikes a balance between the water needs of towns, farmers, industry and the environment. It clarifies the requirements for obtaining groundwater extraction licences and the assessment process under the *Water Management Act 2000*.

The *Water Management Act 2000* defines a number of aquifer interference activities including penetration of, interference with, and obstruction of water flow within, an aquifer. Taking and disposing of groundwater from an aquifer are also defined as being aquifer interference activities.

The AIP requires that for an aquifer interference activity to meet the minimal impact considerations, any change in groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.

Groundwater along the proposal is likely to be used by aquatic ecosystems, and primary industries to account for small-scale domestic use of groundwater. However, this varies locally depending on ambient groundwater conditions.

The AIP also provides a framework for assessing the impacts of aquifer interference activities on water resources. To assess potential impacts, groundwater sources are categorised as either highly productive or less productive, with sub-categories for alluvial, coastal sands, porous rock, and fractured rock aquifers. For each category, there are a number of prescribed minimal impact considerations relating to water table and groundwater pressure drawdown, and changes to groundwater and surface water quality. These are discussed in Section 5.2 for the relevant groundwater sources potentially impacted by this proposal.

2.4.2 NSW Water Quality Objectives

The NSW Government has developed Water Quality Objectives that are consistent with the National Water Quality Management Strategy, and in particular, with the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018). The water quality objectives relate to fresh and estuarine surface waters. Groundwater quality must therefore be maintained to a level that does not degrade any receiving surface water environments. Further discussion of these guidelines is included in Technical Paper 7 (Jacobs, 2020a) of the Environmental Impact Statement.

2.4.3 NSW Groundwater Dependent Ecosystems Policy

This proposal has the potential to impact Groundwater Dependent Ecosystems by reducing the potential groundwater that is accessible to those ecosystems.

The NSW State Groundwater Dependent Ecosystems Policy (department of Land and Water Conservation, 2002) implements the *Water Management Act 2000* by providing guidance on the protection and management of Groundwater Dependent Ecosystems. It sets out management objectives and principles to:

- Ensure that the most vulnerable and valuable ecosystems are protected
- Manage groundwater extraction within defined limits thereby providing groundwater flow sufficient to sustain ecological processes and maintain biodiversity
- Ensure that sufficient groundwater of suitable quality is available to ecosystems when needed
- Ensure that the precautionary principle is applied to protect groundwater dependent ecosystems, particularly the dynamics of flow and availability and the species reliant on these attributes
- Ensure that land use activities aim to minimise adverse impacts on groundwater dependent ecosystems.

3 Assessment methodology

3.1 Overview

The proposal components that would potentially interface with groundwater include:

- Tunnel excavation between The Bays tunnel launch and support site and Hunter Street (Sydney CBD) including the Turnback and Stub Tunnels
- Station and shaft excavation for new metro stations at Pyrmont and Hunter Street (Sydney CBD).

The proposal excavations may cause groundwater inflows to the excavations, and associated groundwater level drawdown. This has the potential to cause the oxidation of acid sulfate soils (if present), as well as potentially impact groundwater quality, groundwater dependent ecosystems, groundwater users and surface water-groundwater interactions.

Minor short-term dewatering may be required for the construction of power supply routes. It is anticipated that the groundwater inflow to excavations for power supply routes would generally be relatively minor (if at all) compared to those experienced by the station or shaft excavations.

The data queries were based within the occurrence area (refer to Figure 4-6) and the assessment of potential groundwater-related impacts arising from this proposal has been carried out as follows:

- Desktop assessment to characterisation of the existing environment including climate; topography; geology; groundwater occurrence, quality and use; existing groundwater users and groundwater dependent ecosystems

  Review of other relevant groundwater assessments, including:

  - Jacobs (2020a) Westmead to the Bays and Sydney CBD Environmental Impact Statement Concept and Stage 1, Technical Paper 7 Hydrogeology
  - Turvey, C; Minchin, W; Merrick, Dr N.P. (2017) West Connex M4-M5 Link, Groundwater Modelling Report. For AECOM Pty Ltd, By NPM Technical Pty Ltd, trading as Hydrosimulations. Reports HS2017/01.
- Site investigations which include the installation of ground water monitoring infrastructure
- Groundwater modelling to assess the potential groundwater impacts, including:
  - Inflows to excavations and shafts
  - Associated groundwater level drawdown
  - Changes to flow directions
  - Impacts to beneficial use (Groundwater dependent ecosystem's (GDE's), registered bores).
- Assessment of the potential groundwater-related impacts listed above based on the modelling results, to satisfy the minimal impact considerations of the NSW Aquifer Interference Policy, and address groundwater related issues raised in the Secretary's Environmental Assessment Requirements

- Recommendations for monitoring and management of identified impacts and risks, including management and mitigation measures as appropriate.

The specific methodologies used for these components of the methodology are described in the following sections and summarised on Figure 3-1.

A preliminary water balance assessment was also carried out. The assessment considers water demand and rates of consumption for this proposal.

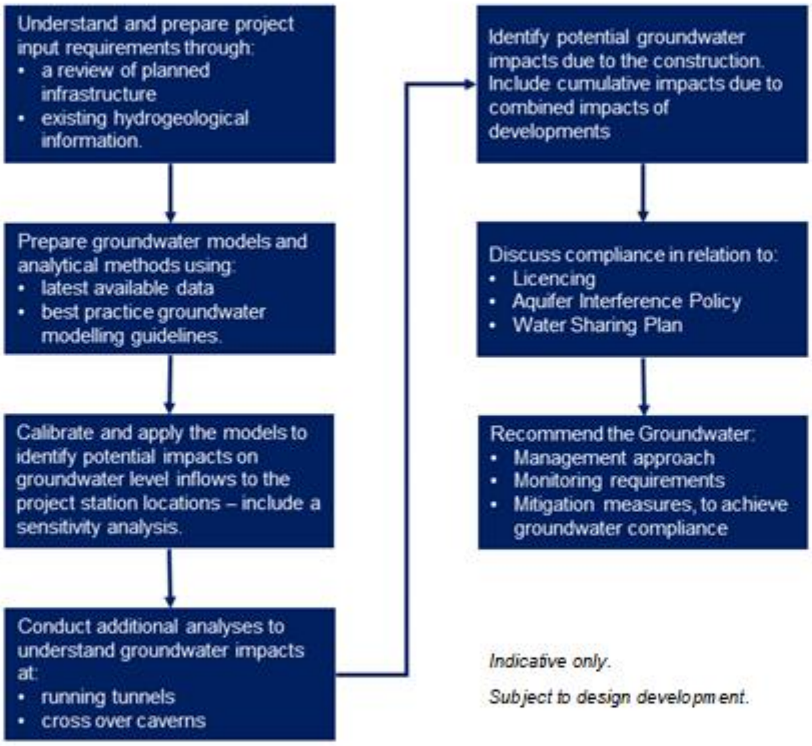

Figure 3-1 Overview of Sydney Metro West between The Bays and Sydney CBD

3.2 Desktop assessment

The desktop assessment involved a review of the existing groundwater environment in proximity to this proposal alignment and construction sites, to assess the potential impacts of this proposal on groundwater during construction.

The following data were collected to inform existing groundwater conditions across this proposal area:

- WaterNSW groundwater bore database (https://realtimedata.waternsw.com.au/) (accessed February 2021)
- The Water Register (http://www.water.nsw.gov.au/water-licensing/registers) for data on existing groundwater users, including Water Access Licence (WAL) holders and stock and domestic users (accessed February 2021)
- The Bureau of Meteorology (BOM) Groundwater Dependent Ecosystems Atlas (http://www.bom.gov.au/water/groundwater/gde/) to identify the location of groundwater-dependent surface water systems and vegetation (accessed February 2021)
- NSW Department of Planning, Industry and Environment (https://www.planning.nsw.gov.au/) to find out information on major project assessments (WestConnex M4-M5 Link and Sydney Metro Chatswood to Sydenham)

- Publicly available maps were also used, including geological maps, topography and drainage maps, and soil maps.

3.3 Site investigations

Site investigations for Sydney Metro West included the installation of groundwater monitoring infrastructure at 65 locations (56 groundwater monitoring wells, and nine single vibrating-wire piezometers). Between The Bays tunnel launch and support site and Hunter Street (Sydney CBD) Station, 14 groundwater monitoring wells, and two single vibrating-wire piezometers have been installed and the data collected has been used to assess current groundwater conditions.

3.4 Groundwater modelling

A three-dimensional analytical element (AEM) groundwater model was developed to support the Environmental Impact Statement. The groundwater model was set up to simulate the existing groundwater environment (pre-construction) and allow assessment of the potential impacts at this proposal construction phases and the long-term implications of the proposal. The groundwater model was created using the software package AnAqSim (Analytical Aquifer Simulator - Fitts, 2011) in accordance with the Australian Groundwater Modelling Guidelines (Barnett et al., 2012). The model was developed based on the definition design, regional hydrogeological data, local geotechnical and hydrogeological data recorded as part of the Sydney Metro West site investigations. In addition, existing regional numerical modelling reports have been used, including the West Connex M4, M5 groundwater modelling report (HydroSimulations, 2017).

The model domain extends from Hawthorn Canal in the west to approximately Darlinghurst in the east, Sydney Harbour to the north and Petersham in the south and includes this proposal alignment from The Bays tunnel launch and support site to the end of the turnbacks including the stub tunnels of the Hunter Street (Sydney CBD) Station. The definition design alignment considered in the model is Version 4.1.

The model incorporates the Pyrmont and Hunter Street (Sydney CBD) Stations caverns and the two access shafts at each of the stations. Both station caverns are designed to be tanked while the four shafts are designed as untanked in the operational phase. Inflows to the tanked structures have been set according to the Particular Specification (PS), Sydney Metro West, Central Tunnelling Package. In addition, for the four untanked shafts, an inflow of 5 litres per day per square meter of surface area was adopted because the modelled inflows for the Pyrmont and Hunter Street Station (Sydney CBD) are generally lower than those of the results presented in Jacobs (2020a), Westmead to the Bays and Sydney CBD, Environmental Impact Statement Concept and Stage 1, Technical Paper 7. The latter report used a slightly higher value of 6.5 litres day per square meter surface area. The value of 5 litres per day per square meter of surface area, adopted for this report is nevertheless considered very conservative because the modelled inflows (discussed later in Section 5.6) are an order of magnitude lower. The design criteria and corresponding seepage flow rate for elements in the operational phase are presented in Table 3-1.

Table 3-1: Design criteria and seepage flow rate for East Tunnelling Package complexes– Operational phase

Elements	Tanked / untanked	Particular Specification	Total allowable inflow
Pyrmont Station Cavern	Tanked	an average of 2.0 millilitres per hour per m² of the concrete lining surfaces; and	0.01 to 0.025 L/sec
Hunter Street Station Cavern (Sydney CBD)	Tanked	a maximum of 5.0 millilitres per hour per m² of the concrete lining surfaces for any 10 metres length of concrete lining	0.01 to 0.025 L/sec
Running Tunnels*	Tanked		0.02 to 0.04 L/sec/km
Pyrmont Station Western Shaft	Untanked		0.43 L/sec
Pyrmont Station Eastern Shaft	Untanked	a maximum of 5.0 L per day per m² surface area for untanked excavations	0.36 L/sec
Hunter Street Station (Sydney CBD) Western Shaft	Untanked	a maximum of 5.0 L per day per m² surface area for untanked excavations	0.55 L/sec
Hunter Street Station (Sydney CBD) Eastern Shaft	Untanked		0.55 L/sec

*Note: *Running Tunnels are not incorporated in the groundwater model at this stage*

Station complexes (cavern and shafts) are untanked during construction.

Running tunnels will be tanked within 24 hours of excavation by placement of the permanent lining within the tunnel boring machines.

For assessment of potential impacts associated with the proposal, the following simulations have been undertaken:

- Steady state pre-construction water table contours
- Construction phase uncalibrated transient model drawdown contours at two years, and inflows at six months, one year, two years, assumed to be at point of sealing of the station caverns (It is not possible to calibrate a transient model to achieve optimal performance in response to an event unless the event has occurred. Predictive transient modelling relies on the calibration of a steady state model and any subsequent checks that can be applied to accommodate temporal variations in measured data; the limitation being that limited amounts of available data such as borehole data, climate data etc., do not represent the full extent of the processes being modelled).

3.5 Impact assessment

The groundwater model results have been applied to assess potential groundwater impacts relating to this proposal.

The groundwater model was used to estimate:

- Groundwater level drawdown at two years, and inflows at six months, one year, two years associated with construction at various stages of excavation.

Potential impacts are assessed by reviewing the predicted groundwater level drawdown due to this proposal against the locations and conditions of existing supply bores; groundwater dependent ecosystems; acid sulfate soils; and interpreted existing groundwater recharge, flow and surface water-groundwater interactions.

The minimal harm criteria presented in the NSW Aquifer Interference Policy (NSW Office of Water, 2012) is addressed with respect to each of these aspects.

Some proposal components such as tunnels were not included in the models. Their impacts on groundwater were analysed separately before conducting a cumulative impact assessment.

3.6 Infrastructure

This proposal infrastructure will include:

- Twin TBM running tunnels between the Bays tunnel launch and support site and Hunter Street station (Sydney CBD), including cross passages, turnback and stub tunnel
- Mined station caverns at Pyrmont and Hunter Street (Sydney CBD), each with two service shafts (western and eastern)
- A cross over cavern just east of the Bays tunnel launch and support site
- Ancillary construction site services (pipe connections electricity).

The proposal is expected to take three years to complete. Assumptions on which infrastructure will be tanked or untanked at different stages of the proposal are stated in section 3.4 above.

4 Existing environment

The existing environment has been characterised based on a desktop review of publicly available information, as well as the results of field investigations specifically completed for Sydney Metro West.

The conceptualisation of the existing geology and hydrogeology relates to the geological setting and groundwater systems that this proposal is situated within, the boundaries of which extend beyond this proposal footprint.

The purpose of this information is to:

- Understand the existing groundwater regime within which this proposal would be implemented
- Understand the physical controls on groundwater flow
- Identify potential receptors that may be impacted by changed groundwater conditions.

4.1 Topography

The proposal falls within the catchment of Sydney Harbour. The Soil Landscapes of Sydney 1:100,000 Sheet (Tille et al., 2009) and Penrith 1:100,000 Sheet (Hazelton et al., 2010) identifies this proposal footprint within the Gymea and Disturbed Terrain soil landscape (Table 4-1).

Table 4-1: Topography

Soil landscape	Topography
Gymea	Undulating to rolling low hills with local relief 20–80 metres and slopes of 10–25 per cent. Sideslopes with narrow to wide outcropping sandstone rock benches (10–100 metres), often forming broken scarps of <5 metres.
Disturbed Terrain	Terrain disturbed by human activity. Local relief is usually <2 metres, but occasionally up to 10 metres. Most areas of disturbed ground have been levelled to slopes of <3 per cent . In terraced cut and fill areas short rises may be steeper than 30 per cent. Microtopography may be hummocky due to truck dumping of fill material. Disturbed areas are often landscaped and artificially drained. Landform elements include berms, cut faces, embankments, mounds, pits and trenches.

The elevation for the proposal at The Bays tunnel launch and support site is primarily at sea level. The Pyrmont Station it is at eight meters Australian Height Datum (AHD) and the Hunter Street Station (Sydney CBD) it is at 22 metres AHD. Most of the waterways are urbanised coastal areas. Some waterways have tidal sections. The topography associated with these soil landscapes are outlined in Figure 4-1.

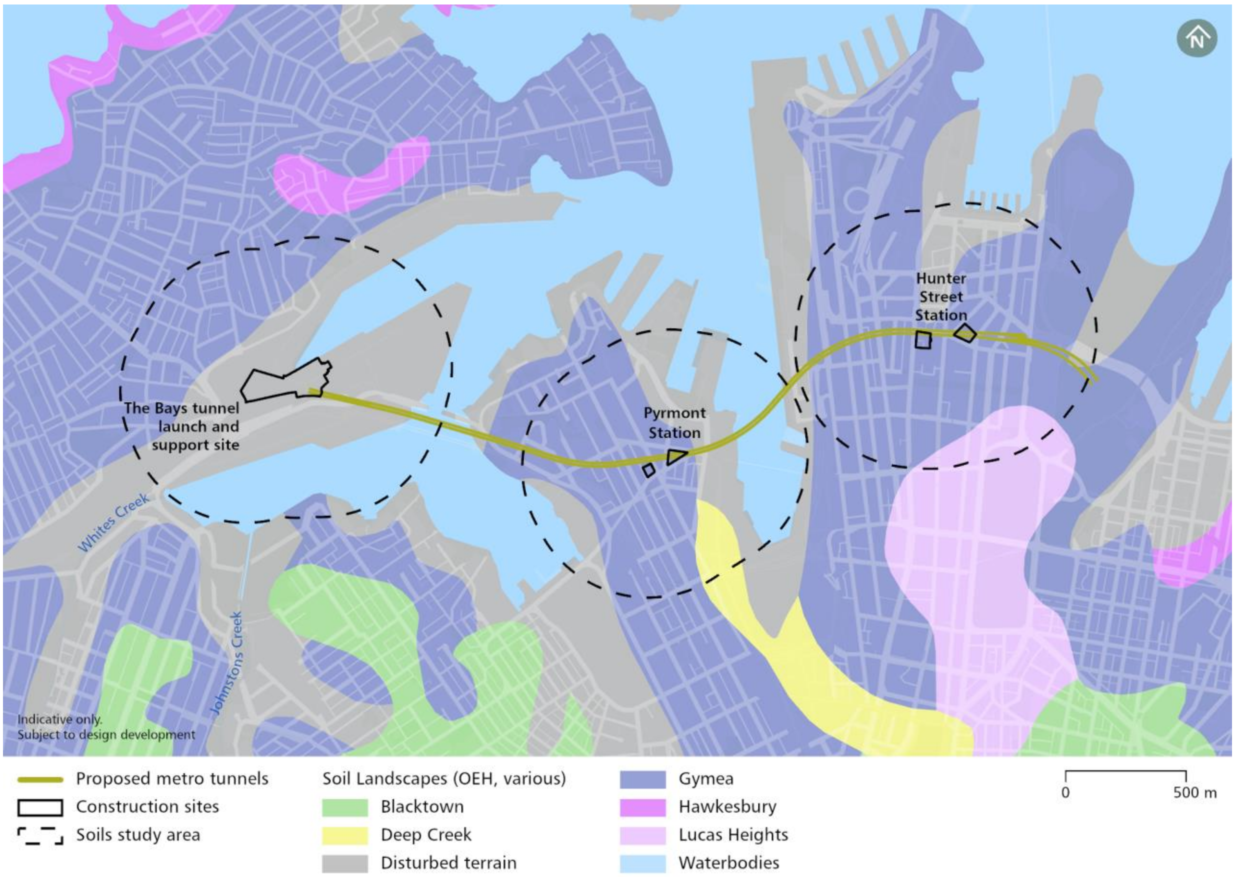

Figure 4-1: Topography Map

4.2 Climate

Review of the Bureau of Meteorology (BOM) rainfall and temperature data for the Sydney Botanical gardens weather station indicates that the mean monthly rainfall within the Proposal ranges between 1.9 millimetres in December 2019 and 468 millimetres in February 2020, with mean annual rainfall for the period 2018 and 2020 being about 1,168 millimetres. The daily temperatures in 2020 at the Sydney Observatory Hill weather station range from 13.6°C in August to 41.2°C in January (Figure 4-2). Part of the rainfall that infiltrates into the ground and reaches the water table to contribute to groundwater is known as the recharge.

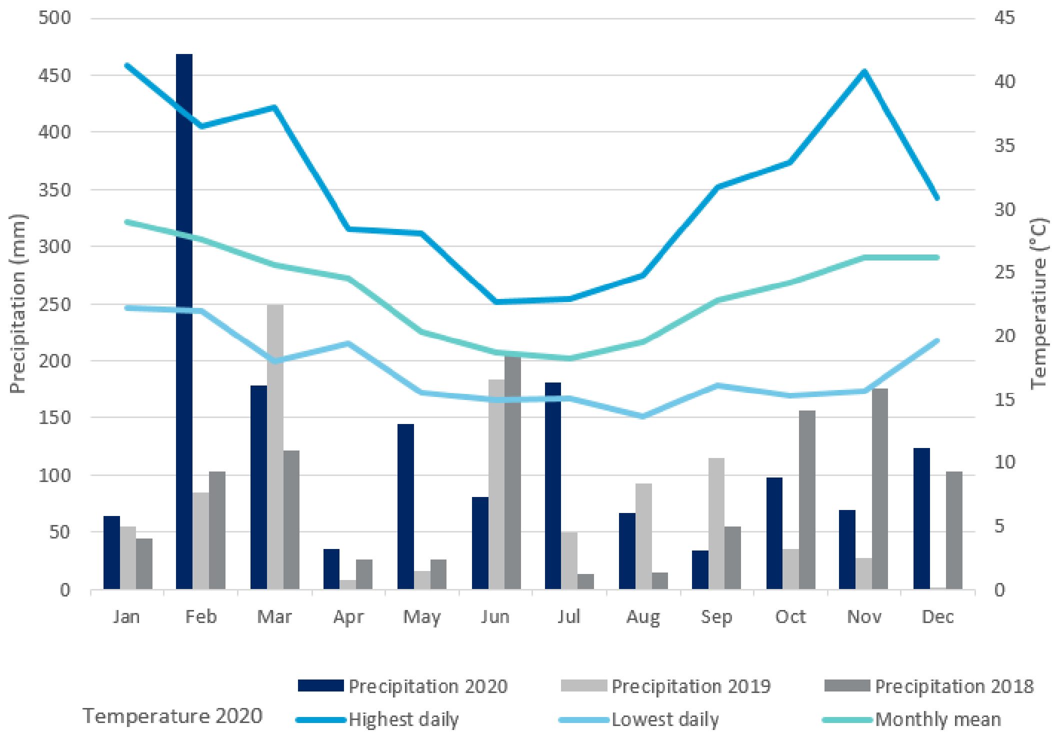

Figure 4-2: Climate chart of Sydney for precipitations in 2020, 2019, 2018 (Botanic Gardens), and temperature in 2020 (Sydney Observatory Hill)

4.3 Geology

The expected geology along the proposal alignment generally comprises of Hawkesbury Sandstone bedrock. Surficial soils comprising of existing fill and residual materials can also be expected to be found on top of the sandstone bedrock with variable thicknesses. Existing fill material of notable thickness can be found at The Bays tunnel launch and support site.

Deep alluvial and marine soil deposits are encountered on the western side of The Bays tunnel launch and support, within Sydney Harbour.

There is the likelihood that the eastern end of The Bays tunnel launch and support site will encounter the Great Sydney Dyke. The Great Sydney Dyke has been identified as being an igneous intrusion comprising typically dolerite material with varying weathering and strength properties.

Also, possible fault zones and a dyke may be encountered about 150 metres to the west of Pyrmont Station, however there is limited geotechnical information along the tunnel alignment through here. Additional geotechnical investigations have been proposed to investigate this area.

Several fault zones have been inferred and identified within the Sydney CBD, at the Hunter Street Station (Sydney CBD) and along the turnback tunnels to the east of this station. Faults are not incorporated in the groundwater model at this stage

Refer to Appendix B for geological long sections along the proposal.

4.4 Acid sulfate soils

Review of the Department of Planning, Industry and Environment acid sulfate soil risk data indicates the following:

- The Bays tunnel and launch support site – entire proposal area is classified as disturbed terrain. Naturally occurring acid sulfate soil is likely
- Pyrmont Station – land east of the proposed eastern construction site is classified as disturbed terrain and land to the west has not been assessed. Acid sulfate soils are likely to occur below natural ground surface in the north-east portion of the proposed Pyrmont Station eastern construction site
- Hunter Street Station (Sydney CBD) – acid sulfate soils are not likely to occur within the proposal area.

A number of known and potential contamination sources (areas of environmental interest - AEIs) or areas of specific geological conditions have been identified within and/or adjacent to the proposal (Mott MacDonald, 2021). To understand the potential interaction of construction activities with potential contaminations, sites have been placed into five categories of potential impact (very low, low, moderate, high and very high). The findings of the assessment are detailed below:

- The Bays tunnel launch and support site - Soils, groundwater and vapour within / beneath the site have been assigned a moderate to high potential impact associated with the historical activities carried out on the site (power station and land reclamation) and reported contamination. AEI with a moderate to high potential impact include former White Bay Power Station, land reclamation (historical use of potentially contaminated fill), ASS and saline soils
- Pyrmont Station construction sites - Groundwater beneath the Pyrmont Station construction sites have been assigned a moderate potential impact associated with general historical activities carried out in the surrounding area and surface and reported elevated concentrations of metals in groundwater from previous investigations. AEI with a moderate to high potential impact include general historical commercial and industrial use (including rail yards), ASS and saline soils
- Hunter Street Station (Sydney CBD) construction sites - Groundwater beneath the Hunter Street Station (Sydney CBD) construction sites have been assigned a moderate to high potential impact associated with historical activities carried out in the surrounding area (gasworks and commercial land use) and known/potential contamination at these sites. AEI with a moderate to high potential impact include the former gasworks at Millers Point.

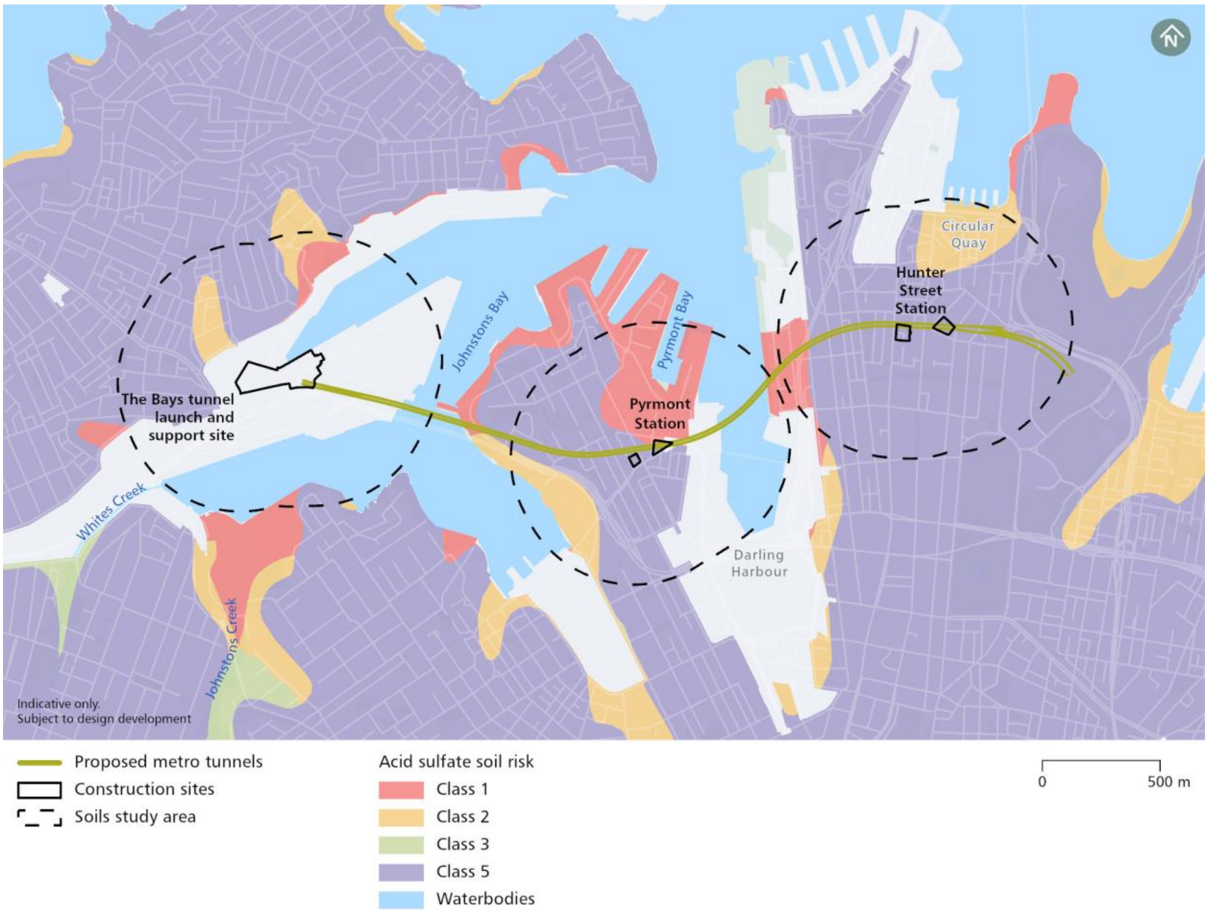

Figure 4-3: Acid sulfate soils risk map

4.5 Salinity

Potential changes that could occur to the groundwater system due to the construction of the tunnel and station excavations may cause salinity impacts. Salinity impacts may include locally severe salt scalding across landscape elements, damage to buildings and infrastructure, fluvial and sheet erosion, high in-stream salinity, localised waterlogging, flood hazard, and a potential decline in water quality.

The spatial information system, eSPADE, managed by the former NSW Office of Environment and Heritage (2019b) presents public soil and land information in the NSW Soil and Land Information System. The overall salinity hazard for the proposal has been identified as 'moderate' for The Bays and waterfront areas of Pyrmont and Sydney CBD. These areas have moderate impact to land salinity, low salt load export and moderate impact to water quality. The overall salinity hazard for areas of Pyrmont and Sydney CBD that are not immediately adjacent to the water are identified as 'very low risk'. These areas have low impact to land salinity, low salt load export and low impact to water quality. Refer to Figure 4-4 for the overall salinity hazard for the proposal tunnel alignment.

In contrast, the NSW Department of Primary Industries (Winkler et al, 2012) reports very high salinity hazard along the coast of Sydney Harbour. Whereas very low salinity hazard is reported for Sydney CBD.

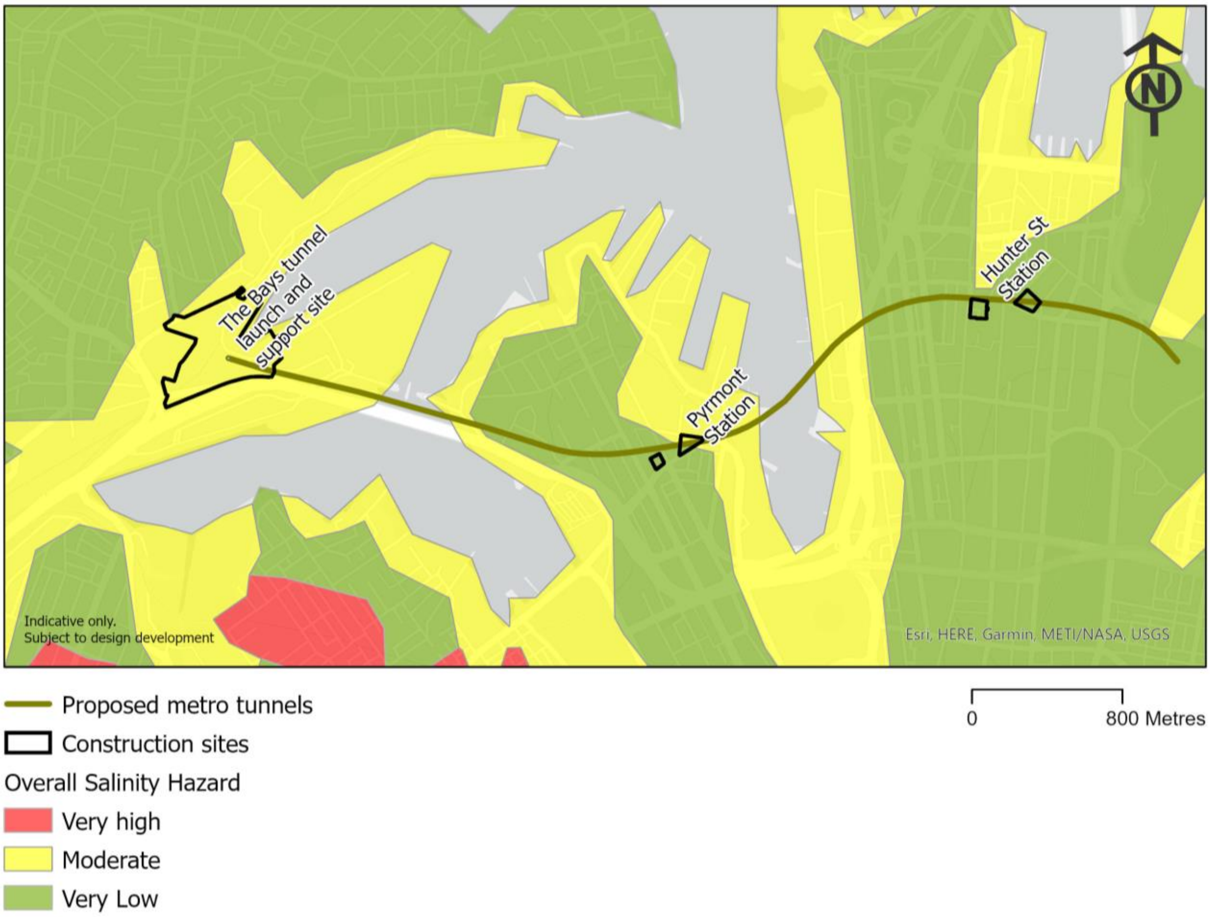

Figure 4-4: Salinity hazard

4.6 Groundwater

4.6.1 Site investigation - Groundwater Levels

Groundwater is known to occur in the soil profile and within the fractured/porous rock along the alignment. A review of registered boreholes with Department of Primary Industries (DPI) identified the locations of groundwater bores within the proposal area (Figure 4-5). These locations confirmed that there are no registered groundwater users within the proposal area, but some monitoring bores are present. In addition to registered bores there are several other sources of groundwater monitoring locations (Figure 4-6) due to site investigations in the proposal area. The site investigations for Sydney Metro West indicate that groundwater levels in the soils along the alignment are generally shallow (typically between one metre and five metres below ground surface) (Golder-Douglas, 2020a; Golder-Douglas, 2021). Other projects in the vicinity of the proposal (Sydney Metro Chatswood to Sydenham, WestConnex – M4-M5 Link) also indicate that the groundwater levels in the soils along the alignment are generally shallow and typically between one metre and five metres below ground surface.

Where adjacent piezometers are screened separately in soil and rock horizons, the data indicates that there is generally a hydraulic connection between the soil and rock aquifers (same groundwater level elevation). At some locations a perched water table may be present within the soils, due to a separation caused by the low vertical conductivity of the soil profile or underlying layer.

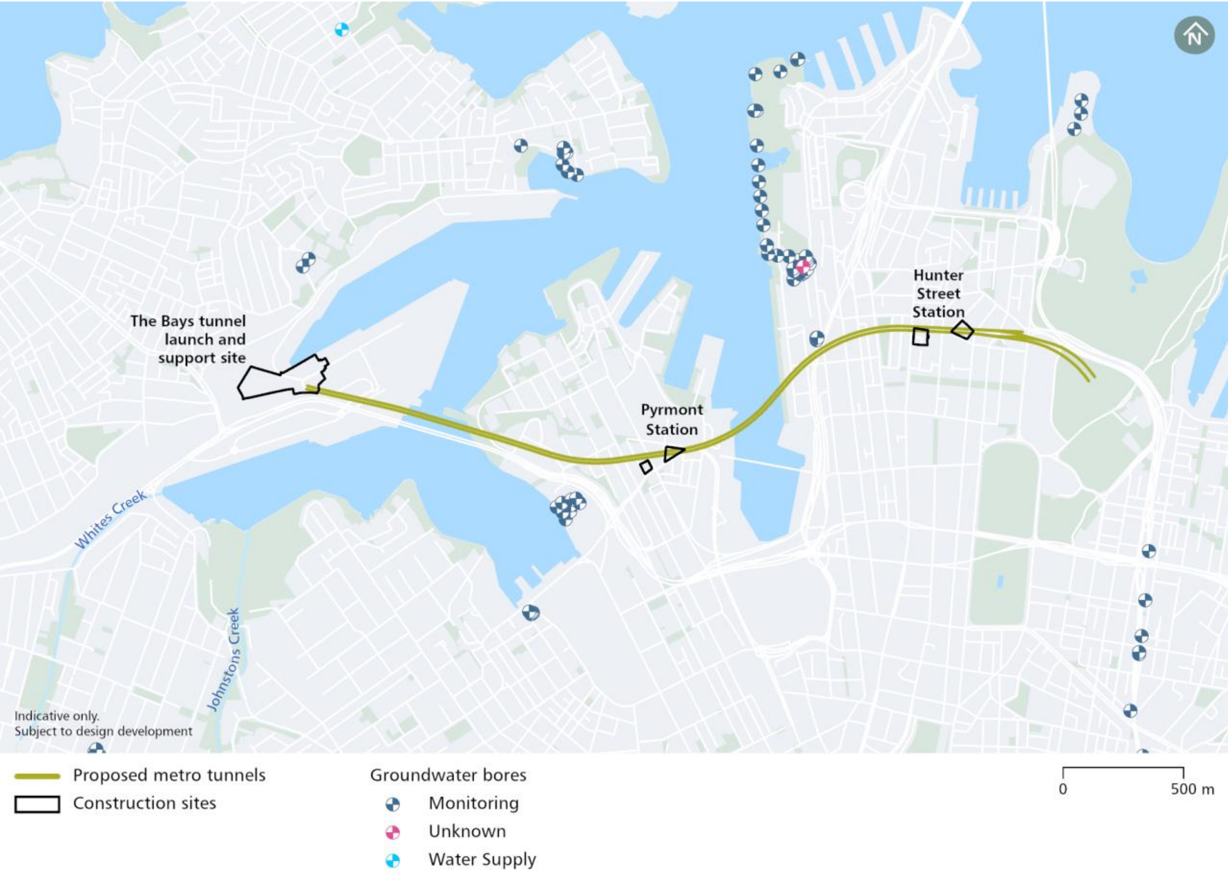

Figure 4-5 Location of registered groundwater bores within the proposal area

A review of groundwater levels from boreholes presented in Figure 4-5 sources was conducted in the vicinity of the alignment, but also looked at the broader groundwater model for better calibration. Groundwater levels in the proposal area (Figure 5-1) are generally shallow and tend to mimic topography with groundwater levels being higher on hills and shallower adjacent creeks and bays. The depth to groundwater also has a topographic effect with deeper groundwater in elevated areas and shallower in low lying areas.

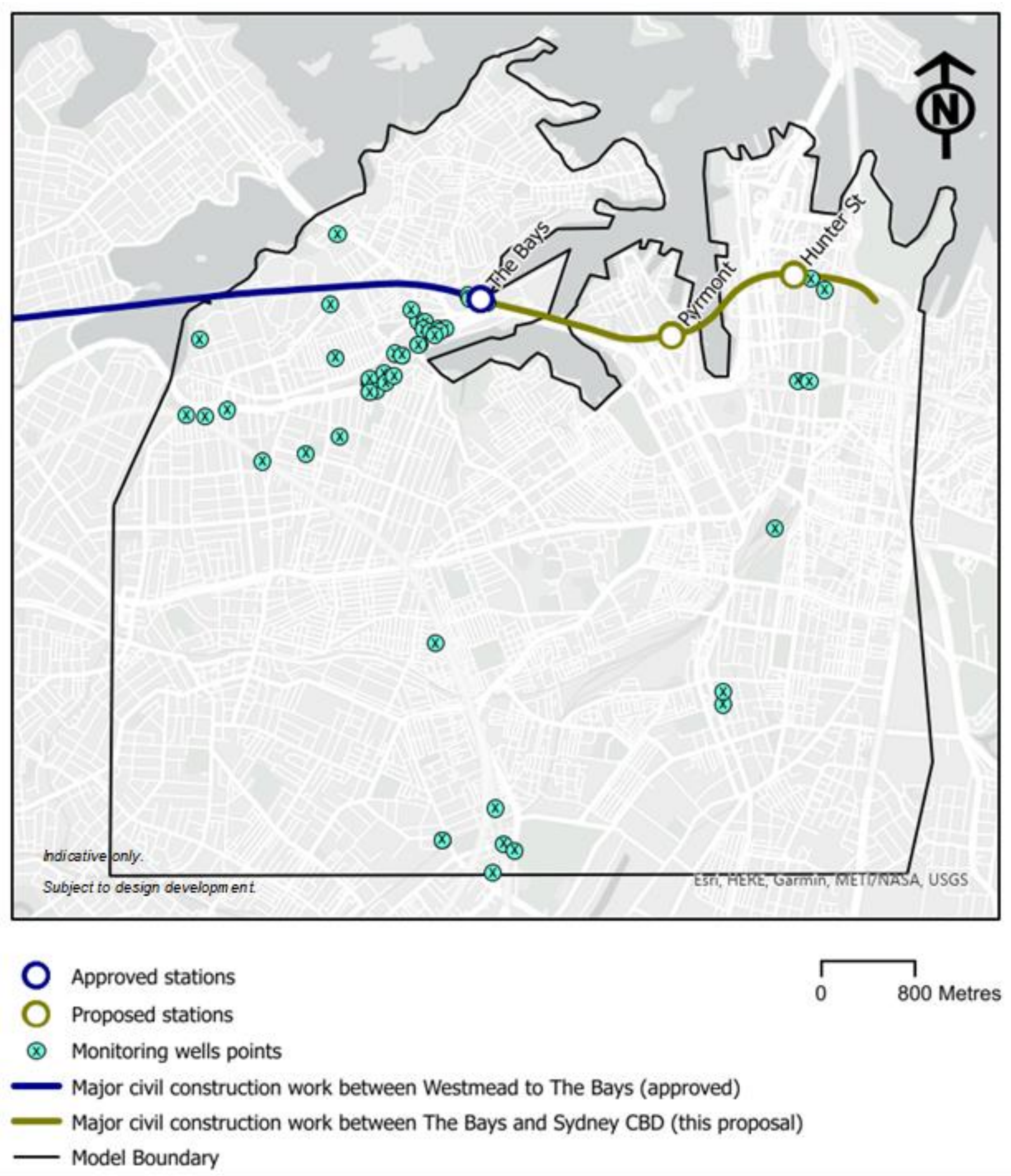

Figure 4-6: Location of groundwater level monitoring points

Figure 4-6 presents reported groundwater in the vicinity of the alignment based on various site investigations. The relevant investigations include Sydney Metro West (this data indicates that groundwater levels in the soils along the alignment are generally shallow (typically between one metre and five metres below ground surface) (Golder-Douglas, 2020a; Golder-Douglas, 2021); (WestConnex M4-M5 Link and Sydney Metro Chatswood to Sydenham). Available data is limited at many locations, and the approximate typical levels listed may not represent groundwater levels in the immediate vicinity of the construction sites.

Groundwater flow is from areas of higher ground towards creeks or drainage lines and the harbour where it discharges. The groundwater system along the alignment on land is considered to be impacted by existing basements, tunnels and shafts, especially in the Sydney

CBD area. Recharge to the groundwater system is also considered highly modified due to the large amount of impervious surfaces, leaking pipes and irrigation of gardens parks and ovals. The monitoring wells in the CBD showed water table disturbance due to previous excavations, basements and tunnels. A uniform groundwater level has been considered in the Hunter Street Station (Sydney CBD) area for groundwater modelling purposes.

Table 4-2: Approximate groundwater levels near construction sites

Construction site	Approximate typical groundwater level in the vicinity of the construction site (mAHD)	Approximate typical depth to groundwater in the vicinity of the construction site in metres below ground level (mbgl)
The Bays (Cross over cavern)	0.8 (SMW_BH066&067)	4.5 (SMW_BH066&067)
Pyrmont Station	-2.4 (SMW_BN052) (Likely impacted by nearby construction activities)	17.4 (SMW_BN052) (Likely impacted by nearby construction activities)
Hunter Street (Sydney CBD) Station	2.97 (SMW_ENV101), -5.5 (SMW_ENV100) (range likely represents highly disturbed groundwater system)	12 (SMW_ENV101), 20.5 (SMW_ENV100) (range likely represents highly disturbed groundwater system)

4.6.2 Groundwater Bore Search

A review of registered boreholes with DPI-Water (Figure 4-5, mentioned further above) identified the locations of groundwater bores within the proposal area. Details of the locations, depths and purpose of these bores are provided in Appendix B. Exact values of the water extraction were not recorded within the source. Rates of 10 metres cubed per day for stock and domestic usages, and 50 metres cubed per day for irrigation and industrial usages may be assumed. However, groundwater bore extraction has not been included in the groundwater model due to no water supply bores being located within proximity of the alignment. However, groundwater extraction does occur through inflow to basements and tunnels especially in the CBD area. There is no available information for the large number of basements therefore a conservative estimate of the groundwater elevation has been adopted in the groundwater model.

4.6.3 Surface water-groundwater interaction

Interactions between surface water and groundwater in the vicinity of the proposal alignment is expected to be minimal due to:

- The area being highly urbanised with predominantly impervious surfaces across the catchments, which reduces possible surface water infiltration into soils and underlying groundwater
- A lack of surface water courses within close proximity to the alignment. Surface water courses are generally located south of the alignment outside the area of groundwater drawdown impact
- Water courses in the vicinity are generally lined (they have a concrete base) and therefore are assumed have limited interaction with groundwater

- The dominant groundwater discharge mechanism is drainage towards the harbour
- The running tunnels will be tanked and are required to meet strict inflow criteria limiting groundwater inflow
- The station caverns and shafts will be untanked during the construction stages but the station caverns will subsequently be tanked.

Therefore, drawdown of the groundwater table due to the proposed construction sites is not anticipated to have a noticeable impact on surface water resources (flow) or access (levels).

Sections of the alignment are located adjacent to waterbodies, including at The Bays tunnel launch and support site and Pyrmont Station and the alignment passes under bays within Sydney Harbour in two locations (Johnstons Bay and Cockle Bay). The presence of these water bodies can have an effect on the hydrogeological environment around and along the alignment. Table 4-3 lists the water bodies identified in proximity to the proposed construction sites which have the potential for groundwater to discharge. Figure 4-7 and Table 4-3 lists the waterbodies identified in proximity to the proposed construction sites which have the potential for groundwater to discharge. They could potentially be considered to be receiving waterbodies, but it is more likely that the excavations at the construction sites will become sinks into which groundwater seepage will occur.

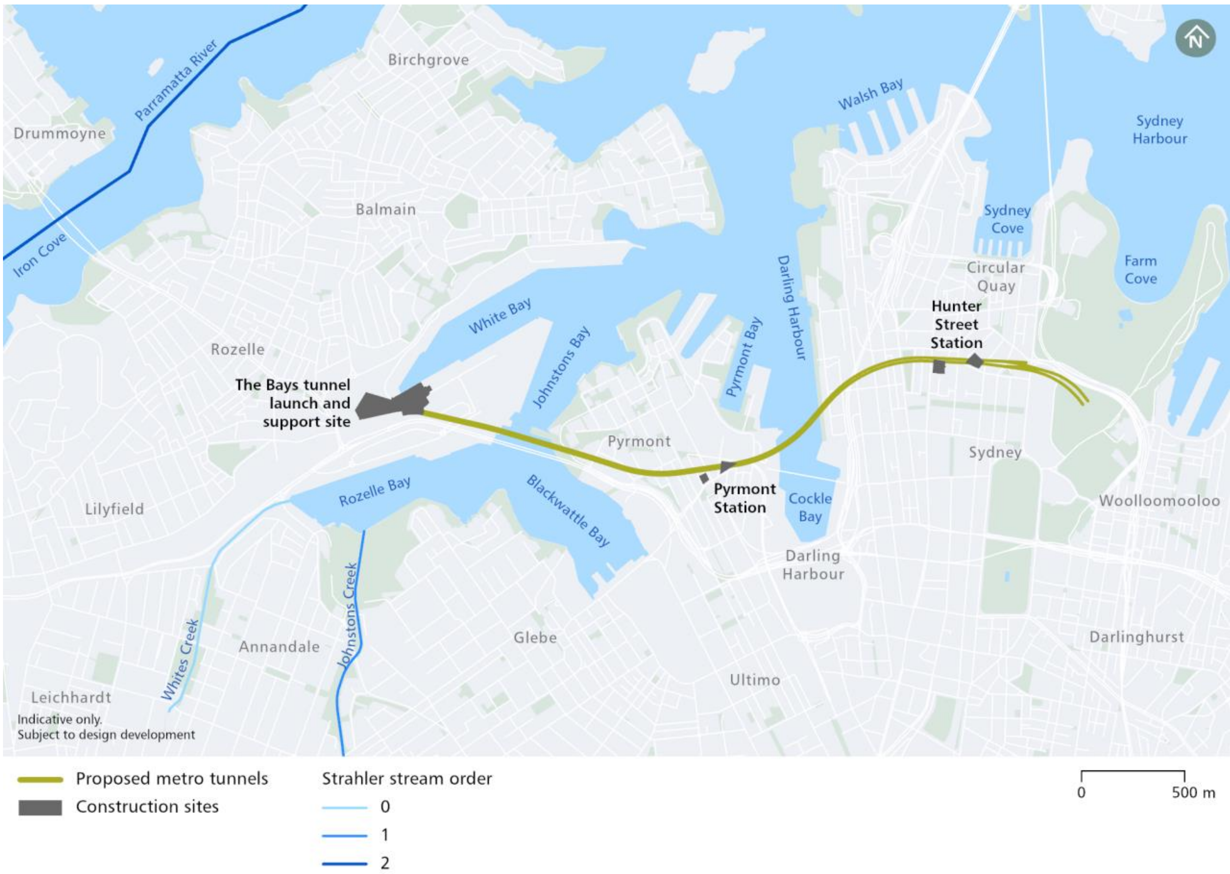

Figure 4-7 Receiving waterbodies and waterways for the proposal

There are no identified surface water courses in proximity to the stations. However, where portions of watercourses are lined, they are considered to have a limited connection with the groundwater system.

Table 4-3: Waterbodies within proximity to the construction sites

Construction site	Drainage line / Waterbody	Approximate distance from site (metres)
The Bays tunnel launch and support site	White Bay	0
Pyrmont Station construction sites	Blackwattle Bay	390
Pyrmont Station western construction site	Cockle Bay	350
Pyrmont Station western construction site	Pyrmont Bay	325
Pyrmont Station eastern construction site	Blackwattle Bay	490
Pyrmont Station eastern construction site	Cockle Bay	225
Pyrmont Station eastern construction site	Pyrmont Bay	240
Hunter Street Station (Sydney CBD) western construction site	Sydney Cove	540
Hunter Street (Sydney CBD) Station eastern construction sites	Sydney Cove	475

Along the proposal the groundwater is anticipated within anthropogenic fill, Quaternary alluvium associated with the bays and Hawkesbury Sandstone (see Section 4.9 for hydrogeological units' description). However, groundwater levels within these units may vary significantly. The water table along the alignment is considered a subdued reflection of the topography with changes dependent upon the landscape position and the impact of neighbouring buried structures, such as deep basements, utility tunnels and other buried transport infrastructure.

Groundwater in the Hawkesbury Sandstone is typically present within secondary structural features, such as fractures, joints, shears and bedding planes. Hawkesbury Sandstone is essentially a fractured rock aquifer. Generally, the hydraulic conductivity of the Hawkesbury Sandstone is relatively low. However, the permeability can vary rapidly by up to three orders of magnitude with the influence of local features such as joint swarms, or dykes.

4.7 Groundwater quality

4.7.1 Typical quality

The quality of groundwater within the Hawkesbury Sandstone regionally is typically of low to moderate salinity, with electrical conductivity ranging between 500 microSiemens per centimetre (µS/cm) and 2,000 µS/cm (about 300 milligrams per litre to 1,400 milligrams per litre as total dissolved solids), and pH values generally between 4.5 and 8. Generally, groundwater is a sodium-chloride type water and is high in iron.

Where Ashfield Shale overlies Hawkesbury Sandstone, the quality of groundwater within the Hawkesbury Sandstone is often influenced by the overlying unit and the groundwater is generally of a higher salinity leading to elevated salinity within the groundwater in the Hawkesbury Sandstone (Australian Government Bioregional Assessments website, www.bioregionalassessments.gov.au).

Adjacent to the harbour groundwater may be influenced by the harbour especially where drawdown of the water table has occurred allowing saline water intrusion. Under natural conditions a wedge of fresh water would exist on top of deeper saline water adjacent to the coast.

4.7.2 Proposal specific quality

Previous site investigations (Jacobs, 2020a) collected groundwater samples from 96 boreholes and 72 monitoring bores, including at The Bays, Pyrmont and Hunter Street.

Laboratory analyses were carried out for various combinations of test parameters (depending on sample) for major ions, heavy metals, total recoverable hydrocarbons (TRH), benzene, toluene, ethyl benzene and xylene (BTEX), polycyclic aromatic hydrocarbons (PAH), nutrients, hexavalent chromium, total and speciated phenols, per- and polyfluoroalkyl substances, volatile organic compounds (VOC), organochlorine (OCP) and organophosphate pesticides (OPP), and tributyltins.

The laboratory analyses found that samples taken from The Bays had concentrations of asbestos, Benzo(a)pyrene and lead exceeded the National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPM) criteria for human health levels. Samples taken from The Bays also had concentrations of copper, zinc, Benzo(a)pyrene, nickel and lead that exceeded the NEPM criteria for ecological levels.

4.7.3 Potential contamination

Jacobs (2020b) identified The Bays tunnel launch and support site as having potential for contaminated groundwater. Contamination could be present in groundwater at concentrations above the NEPM assessment criteria for human health and ecological levels but is likely to be limited in extent. Contaminated groundwater may intersect the construction site for The Bays tunnel launch and support site and the exposure pathways for human or ecological receptors could be present and fully reached during construction. Potential migration of contaminated groundwater towards, and into, the station, shafts and tunnel excavation (which would be constructed under the approved Stage 1), poses a potential exposure risk to site users/workers and adjacent site users, and could potentially reduce the beneficial use of the aquifer.

4.8 Sensitive receiving environments

4.8.1 Groundwater dependent ecosystems

The Bureau of Meteorology Groundwater Dependent Ecosystems Atlas (http://www.bom.gov.au/water/groundwater/gde/) identifies the potential groundwater dependent ecosystems (aquatic, terrestrial and subterranean ecosystems) located in New South Wales.

No potential groundwater dependent ecosystems were identified in proximity to the alignment.

4.8.2 Surface waterways and wetlands

Sydney Harbour has been identified as a receiving waterway of high sensitivity, due to its significance as a key fish habitat (Type 1, highly sensitive). This watercourse has a high conservation or community value, or supports ecosystems or human uses of water that are particularly sensitive to pollution or degradation of water quality.

Although the entire Sydney Harbour catchment is mapped as Key Fish Habitat and classified as Type 1 Key Fish Habitat, White Bay is unlikely to contain significant aquatic habitat due to it being heavily modified for port purposes and therefore not considered Key Fish Habitat in accordance with the *Policy and guidelines for fish habitat conservation and management – Update 2013* (NSW Department of Primary Industries, 2013). No threatened species listed under the *Fisheries Management Act 1994* have potential habitat within White Bay.

Coastal wetlands, as defined by the Coastal Management SEPP, are greater than 500 metres away from all discharge-receiving bays

4.9 Hydrogeology

Information obtained as part of site investigations for this proposal and the desktop review of the Sydney 1:100,000 geological map (Herbert, 1983) (Figure 4-8), shows three major hydrogeologic units in the immediate vicinity of the proposal:

- Anthropogenic (man-made) fill
- Quaternary unconsolidated sediments
- Hawkesbury Sandstone.

Ashfield shales and Quaternary marine sands are located to the south and east of the alignment. Jurassic age dolerite dykes are also known to intrude the Hawkesbury Sandstone, with the Great Sydney Dyke (not shown) crossing the alignment just east of The Bays tunnel launch and support site in the vicinity of the crossover cavern. The geological units are described below, and dykes are discussed further in section 4.9.2.

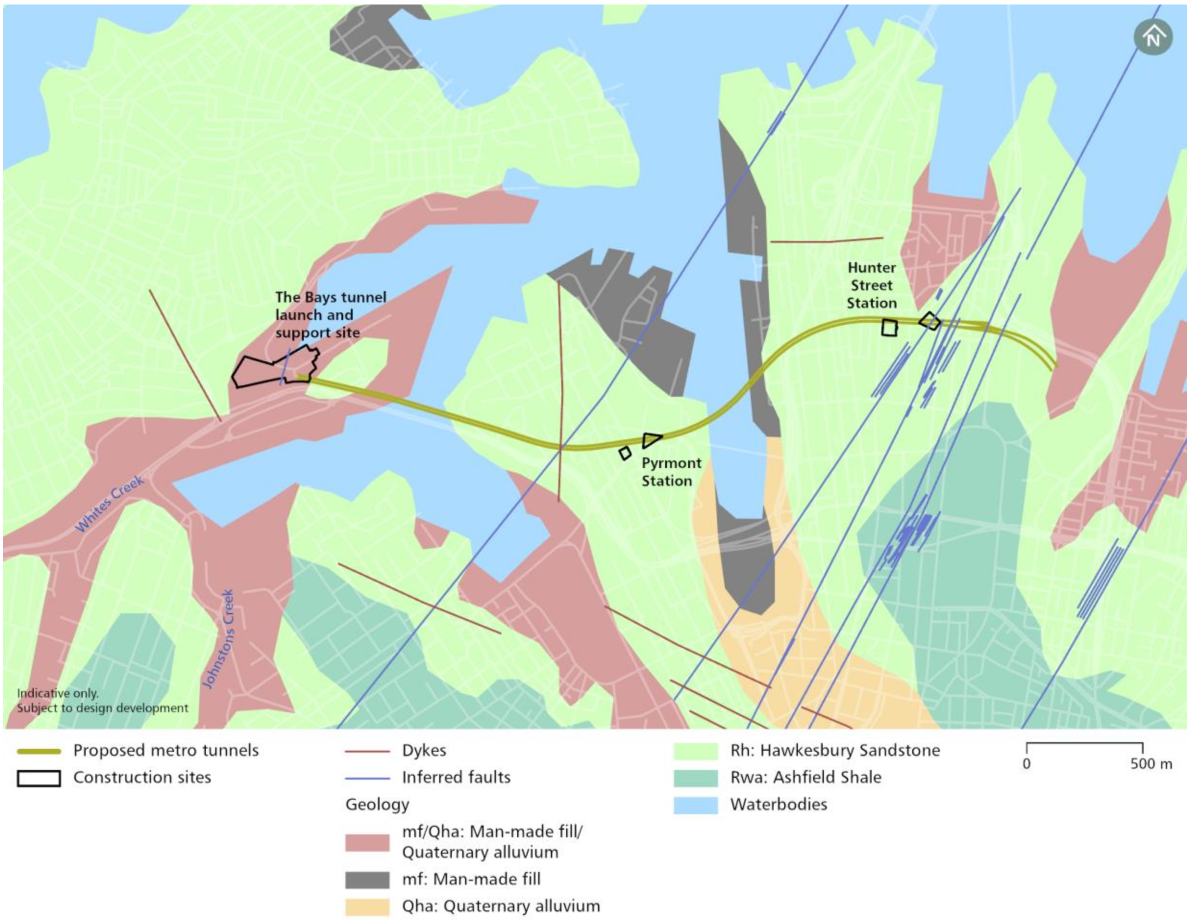

Figure 4-8: Sydney Metro West and geological map

4.9.1 Quaternary Alluvium

Alluvial deposits tend to occur along creeks and floodplains in the proposal area. The alluvial deposits are usually observed to be coarse clean sands and gravels. These materials can form shallow localised unconfined aquifers that are typically responsive to rainfall, streamflow, and tides. The alluvium records hydraulic conductivity ranges from 0.1 metres per day to 1 metre per day in literature (Turvey et al., 2017).

4.9.2 Jurassic intrusions

The Jurassic age sedimentary sequences of the Sydney basin are intruded by Triassic age dolerite dykes. These dykes can act as barriers to lateral groundwater movement or conduits that enhanced pathways for groundwater (O'Neill et al., 2013). Most groundwater is encountered along the margin of the dykes and although permeability may be enhanced inflows are generally in the order of 1 to 2 litres per second when intersected in tunnels (Dale, Rickwood and Wong, 1997).

4.9.3 Triassic Ashfield Shale

This Triassic Ashfield Shale has a thickness ranging from 100 metres to 150 metres (Ransley, 2018). Unlike the previous layers, this layer is considered to be an aquitard due to its poor ability to transmit water through its fine-grained sequence and tight bedding planes. Groundwater flow within this layer usually occur through fractures and joints although the bulk hydraulic conductivity is typically low, in the order of 1 x 10-5 m/day to 1 x 10-2 m/day (Turvey et al., 2017).

4.9.4 Triassic Hawkesbury Sandstone

This unit is part of an aquifer system that runs across the whole Sydney Basin which covers an area of approximately 20,000 km^2 (Lee, 2009), including Stage 1 of the previously approved proposal and within this proposal. Groundwater flow in this layer is dominated by secondary porosity and fracture flow along joints and shear zones (Herron et al., 2018). This unit is considered a semi-confined aquifer (Danis, 2014). The hydraulic conductivity from site specific testing ranges from 1 x 10-6 to 1 x 10-3 m/day in the Proposal (Figure 4-9) and is typically in the order of 1 x 10-3 m/day to 1 x 10-1 m/day (Turvey et al., 2017). Calibrated values adopted in the groundwater model (Figure 4-9 and Table 5-2) are in the range of literature values.

4.9.5 Hydraulic permeability

The major geological unit that would be intersected by this proposal elements within the Hawkesbury Sandstone. A large number of lugeon packer test values are available for this unit across the Sydney area as shown on (Figure 4-9) from proposal site investigations and literature values. The data indicates over three orders of magnitude range in permeability and a generally declining permeability with depth. The shaded area indicates the range of permeabilities adopted in the calibrated model which are closer to values used in the WestConnex M4-M5 Link numerical model (Hydrosimulations, 2017).

A comprehensive review of field hydraulic testing data (Hydrosimulations, 2017) indicated permeability values obtained from lugeon packer tests (and other short duration test methods) often underestimate the bulk rock permeability but do provide an indication of the lower end range.

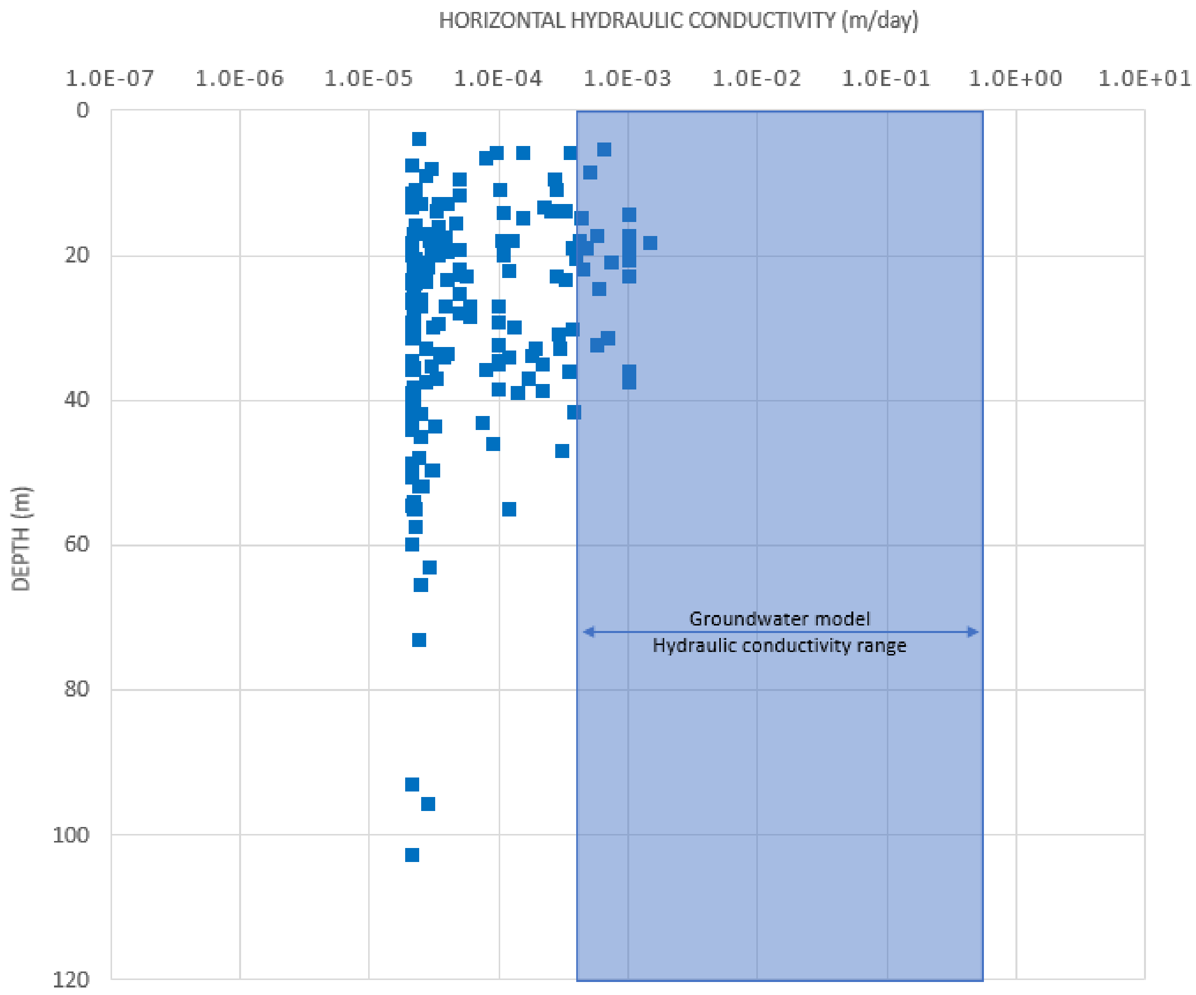

Figure 4-9: Hydraulic conductivity from site investigation packer tests in the Hawkesbury Sandstone

4.10 Groundwater inflow in existing infrastructures

Groundwater inflow are usually more prominent for existing structures like tunnels, and primarily designed to be free draining, under the restriction of a maximum inflow rate of 1 litre per second, per kilometre during operation. For this proposal, water inflow into Sydney tunnels have been recorded (Hewitt and Smirnoff, 2005, Design and Construction of Epping to Chatswood Rail Line Tunnels, Groundwater control for Sydney Tunnels, Proceedings - Rapid Excavation and Tunnelling Conference) to vary from 0.6 litre per second, per kilometre to 3 litre per second, per kilometre (Table 4-4). The groundwater inflow to these existing infrastructures were not included in the groundwater model as the values were negligible and there is limited water level information to allow calibration of the model against.

Table 4-4: Groundwater inflow into tunnels

Tunnel	Type	Length (km)	Span/diameter (m)	Maximum rock cover (m)	Long-term measured inflow (L/s/km)
Northside Storage	Water	20	6	90	0.9 (10 without extensive grouting)
Epping to Chatswood	Rail	13	7.2 (twin)	60	0.9
M5 East	Road	3.9	8 (twin)	60	0.8 - 0.9
Eastern Distributor	Road	1.7	12 (double deck)	40	1
Hazelbrook	Water	9.5	2	50	0.1
Cross City	Road	2.1	8 (twin)	53	<3
North West Rail Line	Rail	15.5	7.2 (twin)	67	<1

4.11 Conceptual hydrogeological model

A conceptual hydrogeological model sets out how the hydrogeology of the aquifer system which will interact with this proposal is understood to behave and provides the basis for the development of a groundwater model.

This proposal runs from just east of The Bays station excavation site (to be constructed under the Stage 1 planning approval) to the end of the turnback and stub tunnels, east of the Hunter Street Station (Sydney CBD) (Figure 4-8). Over this alignment the station cavern, shafts, tunnels and associated infrastructure will encounter the following geology, from shallowest to deepest, Anthropogenic fill, Quaternary alluvial and colluvial sediments, Hawkesbury Sandstone and Tertiary Dykes. The alignment will also pass under sections of the harbour such as Johnstons Bay and Cockle Bay.

Groundwater along the alignment is contained within all geological and anthropogenic units and the water table is a subdued reflection of topography. Groundwater flow is from areas of elevation towards the harbour.

In natural catchments, groundwater recharge is dominated by rainfall infiltration especially where there is exposed sandstone, soils, fill and alluvial material. Other sources of recharge may include leaking water pipes, irrigation of parks, gardens and ovals and stormwater pipes. However, in urbanized catchments with a high proportion of impervious surfaces such as in Pyrmont and Sydney CBD, the potential for rainfall infiltration is very low.

Groundwater discharge is dominated by outflow to the harbour. Other pathways include evapotranspiration, baseflow to creeks, groundwater pumping and inflow to tunnels, basements, and excavations.

West of The Bays tunnel launch and support site, the West Connex Roselle Interchange is a drained tunnel system which has resulted in the groundwater in the vicinity being drawn down to the invert of the lowest tunnel. In the vicinity of the Hunter Street Station (Sydney CBD) the groundwater system is considered highly disturbed due to the large number of existing tunnels, excavations and impermeable barriers (e.g., tanked basements) to groundwater flow.

For the purposes of modelling existing hydrogeology of this proposal, the potential impact of existing tunnels, basements and excavations in the CBD area and the Roselle Interchange have not been accounted for in the model and average groundwater levels have been assumed (without the levels impacted by existing infrastructure or current development proposals). This assumption results in a conservative (overestimate) of the preconstruction water table elevation and enables a comparison with future construction and operational states of this proposal.

No tanked tunnel, station cavern or shaft is completely watertight and all elements of the proposal will allow some groundwater to enter. The amount entering each element of the proposal is as per the design criteria (Table 3-1).

The general groundwater flow direction at each of the station sites is away from the construction sites as they sit near the top of ridge lines and flow will be generally to the east, north and west.

During construction, inflows to station caverns would be drained up until the station caverns are sealed and waterproofed. The tunnels would be lined with pre-cast segments, however there is potential of higher inflows during tunnel boring machine excavation at the cutting face if it is operating in open face mode. If the tunnel boring machine excavation is undertaken using Earth Pressure Balance (EPB) or Slurry Mode, as would be the case under the harbour for instance, inflows would be minimal.

5 Hydrogeological impact assessment

5.1 Excavation and groundwater management strategy

This proposal will involve excavation of the access service shafts and station caverns at Hunter Street and Pyrmont and twin running tunnels between the Bays tunnel launch and support site and Hunter Street, including cross passages, turnbacks and stub tunnels as well as ancillary infrastructure. Both the Hunter Street and Pyrmont stations will be excavated as mined caverns with associated service shafts. A cross over cavern will be mined just east of the Bays tunnel launch and support site.

The Pyrmont Station and Hunter Street Station (Sydney CBD) caverns are designed as tanked and the service shafts at both station locations are drained. During construction they will be drained across all horizons intersected by the excavations. The station caverns will be sealed to achieve tanked conditions at the end of the construction period. Modelling assumes tanked condition during construction which is assumed to span two years. Two years being the time required to complete the excavation within the three-year construction stage. A conservative modelling approach assumed an instantaneous excavation at the start of the excavation period. Future modelling of long term conditions would accommodate design specifications (to be confirmed) which may consist of station caverns that are tanked and the shafts drained.

The running tunnels have not been explicitly modelled as it is assumed, they will effectively be sealed by installation of the segmental lining as the tunnels progress. Inflows to the face of the tunnel have modelled analytically assuming open face conditions (no inflow controls).

5.2 Analytical element model

Assessment of the potential impacts of the construction of stations and tunnels on the groundwater system was carried out using the Analytical Aquifer Simulator (AnAqSim™) software. AnAqSim employs the analytic element method (AEM), which superimposes analytic solutions to yield a composite solution consisting of equations for head and discharge as functions of location and time. AnAqSim uses a variation of the AEM that divides the modelled region into subdomains, each with its own definition of aquifer parameters and its own separate AEM model (Fitts, 2011). This subdomain approach allows for a high degree of flexibility with respect to a model's heterogeneity, anisotropy, and layering.

5.2.1 Model domain and boundary conditions

The extent of the groundwater model focuses on the tunnel alignment within an area approximately 8 kilometres by 8 kilometres. Natural groundwater divides have been used such as canals and creeks to the west, the harbour to the north and topographic highs to the east and south as the boundaries. The boundaries are also set far enough from the alignment so as not to interact with the alignment.

The model boundaries were set to accommodate potential influence from neighbouring systems (Figure 5-1) and also considered the need to include the construction of the adjoining The Bays tunnel launch and support site, which was approved in Stage 1.

The western Flux specific boundary assumes no flow of zero flux across this boundary as groundwater flow is essentially perpendicular to this boundary. The eastern and southern head specific boundary has applied heads inferred from the WestConnex M4-M5 Link regional model by HydroSimulations (2017) and matching regional data points. The boundary is broken into a series of segments to match the head along the boundary which ranges between zero metres AHD and 20 metres AHD.

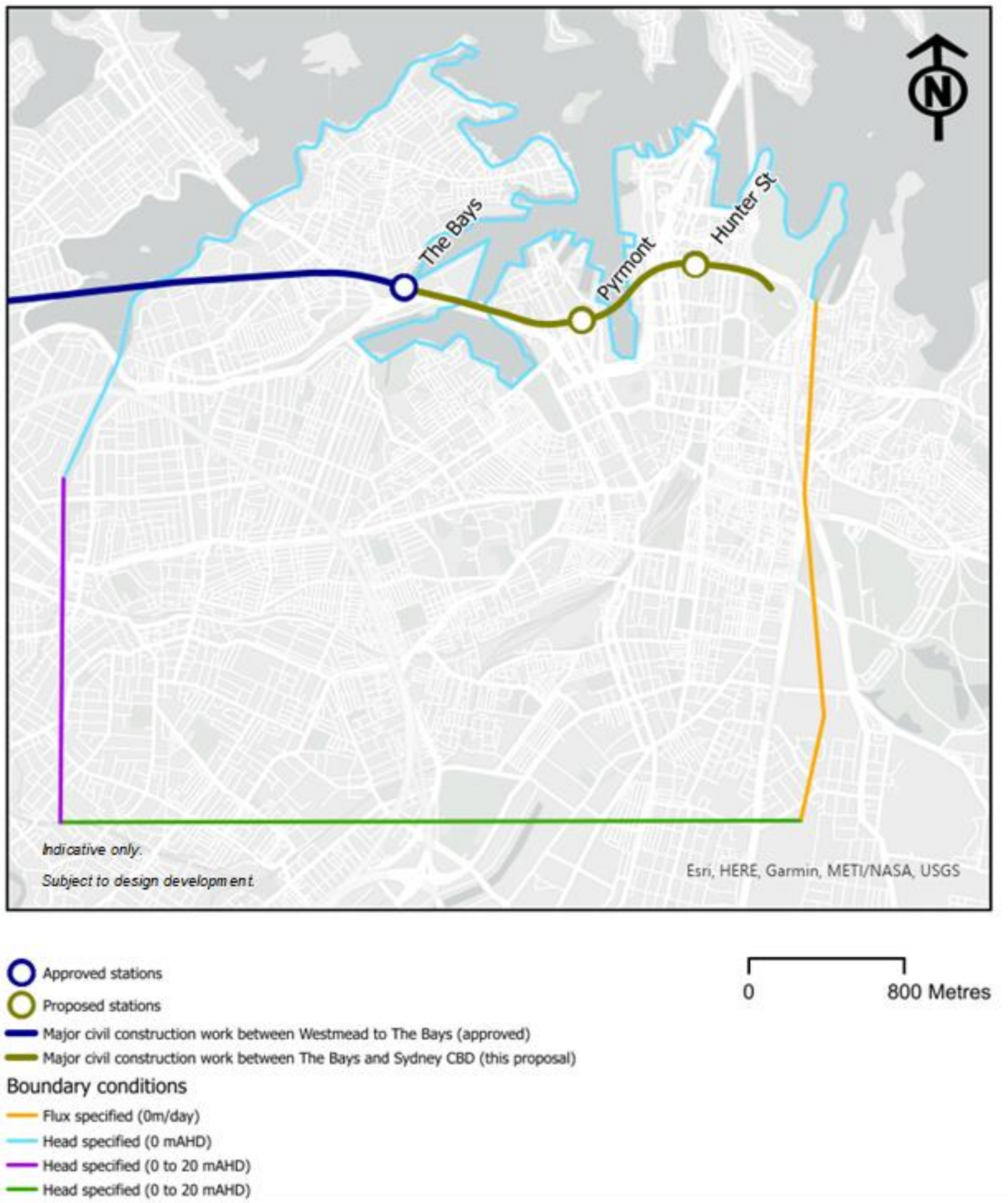

Figure 5-1: Steady State calibration groundwater levels, and boundary conditions

5.2.2 Layers and subdomains

The groundwater model surface is based on the Sydney 1:100,000 geological map (Herbert, 1983) (Figure 4-8) and is vertically organised based on geological long sections (Appendix C to Appendix G) (Figure 4-8). The hydrogeological units (dimension and properties) encountered vertically along this proposal alignment were used in the model. The model has six main layers and is further subdivided along the alignment to represent the varying hydro-geological units and rock classes along the tunnel alignment (Table 5-1).

Table 5-1: Groundwater model layer elevations

Layer number	Elevation (mAHD)
1	20 to 1
2	1 to -8
3	-8 to -15
4	-15 to -27
5	-27 to – 50
6	-50 to -100

The preliminary steady state model was calibrated based on hydraulic properties, and net groundwater recharge (Table 5-2). The calibrated model adopted hydraulic values are within the upper range of those measured during site investigation (Figure 4-9) and within the range of published literature values. Net groundwater recharge is zoned based on geology (refer to Figure 4-8) and ranges between 3.0E-06 and 7.0E-05 m/day which equals to about <0.01 per cent and 0.2 per cent of the long-term mean annual Sydney rainfall of 1,213 millimetres, however these were not calibrated for land-use types observed within the proposal area (i.e. open area, parks, ovals, roads, buildings and underlying network of potentially leaking pipes etc.) as this would have unduly complicated the model through multiple recharge domains. The adopted values through the calibration process account for land use by default (for example, the Botany sands has a mix of open space and built-up areas and the recharge reflects this).

5.2.3 Hydraulic Parameters

The adopted hydraulic parameters (Table 5-2) were chosen based on site investigation data, published literature values and values adopted for the WestConnex M4-M5 Link road tunnel model (Hydrosimulations, 2017). The values were than refined by trial and error to provide the best match to the calibration targets. The calibrated steady state model faithfully reproduces the groundwater flow system within the model domain and is considered sufficiently representative for preliminary impact assessment.

The model has six hydro-geological units based on geology. The model has six layers covering the whole model domain. Within the model there are numerous sub domains where the hydrogeological unit thickness and properties are varied to better represent the conditions such as at the stations. The range of values shown on the table refer to the values used within the sub-domain of each layer.

Refer to the geological long sections for adopted layers and sub domains in Appendix C to G.

Table 5-2: Groundwater model parameters

Layer*	Hydraulic conducti-vity horizontal (m/day)	Hydraulic conducti-vity vertical conductivity ratio	Porosity	Specific Yield	Storativity	Net Recharge (m/day)
Man-made fill	1 to 0.1	1	0.25	0.2	1.0E-05	1.7E-05
Quaternary Alluvium	3.6 to 1	0.5	0.25	0.2	1.0E-05	7E-05 to 1.7E-05
Ashfield Shale	2.80E-02 to 7.71E-05	0.1 to 4E-03	5E-02	1E-02	1.0E-05	1.4E-05
Hawkesbury Sandstone Class III/IV	0.88 to 8E-02	0.5 to 2E-02	0.22	1E-02	1.0E-05	7E-05 to 3E-06
Hawkesbury Sandstone Class I/II	0.6 to 8E-04	0.02 to 0.04	0.2	2E-02	2E-06	-
Botany Sand	2 to 0.015	0.5 to 2E-02	0.4 to 5E-02	0.2 to 1E-02	1.0E-04 to 2E-04	3.4E-05

*Note: *range is provided as some layers occur in a number of domains within the model and have different permeabilities depending on the geology or importance of the location.*

5.3 Calibration

The preliminary steady state model calibration considers matching with the local groundwater divide lines, flow direction and assessed modelled water levels against recorded water levels (Figure 5-1). Effort has been made to use site investigation data in the proposal and previous works as part of the calibration (WestConnex M4-M5 Link, 2017; Sydney Metro West Concept and Stage 1 EIS Westmead to the Bays), with the range of hydraulic parameters and recharge estimates to constrain the calibration. The model setup has been updated to accommodate anisotropy and vertical leakage across layers.

Steady-state flow was simulated to represent the average pre-construction conditions. The groundwater model's calibrated steady state is considered to reasonably reproduce spatially distributed water levels, flow directions and gradients (Figure 5-2). Some discrepancies were found between observed heads and modelled heads (Figure 5-3). The discrepancy between some modelled and observed heads are thought to be related to impacts from specific infrastructure, such as tunnels and basements or the water level information which pre- or post-dated groundwater impacts. The simulated steady state water table is therefore considered conservative with respect to levels (especially in the CBD area) and hydraulic conductivities with respect to the packer tests conducted on site.

Simulation of inflows and drawdown during construction were undertaken transiently. The transient model was not transiently calibrated against monitoring or aquifer testing data. The transient model uses the calibrated steady state model to assess the construction impacts and is considered suitable for preliminary assessment purposes.

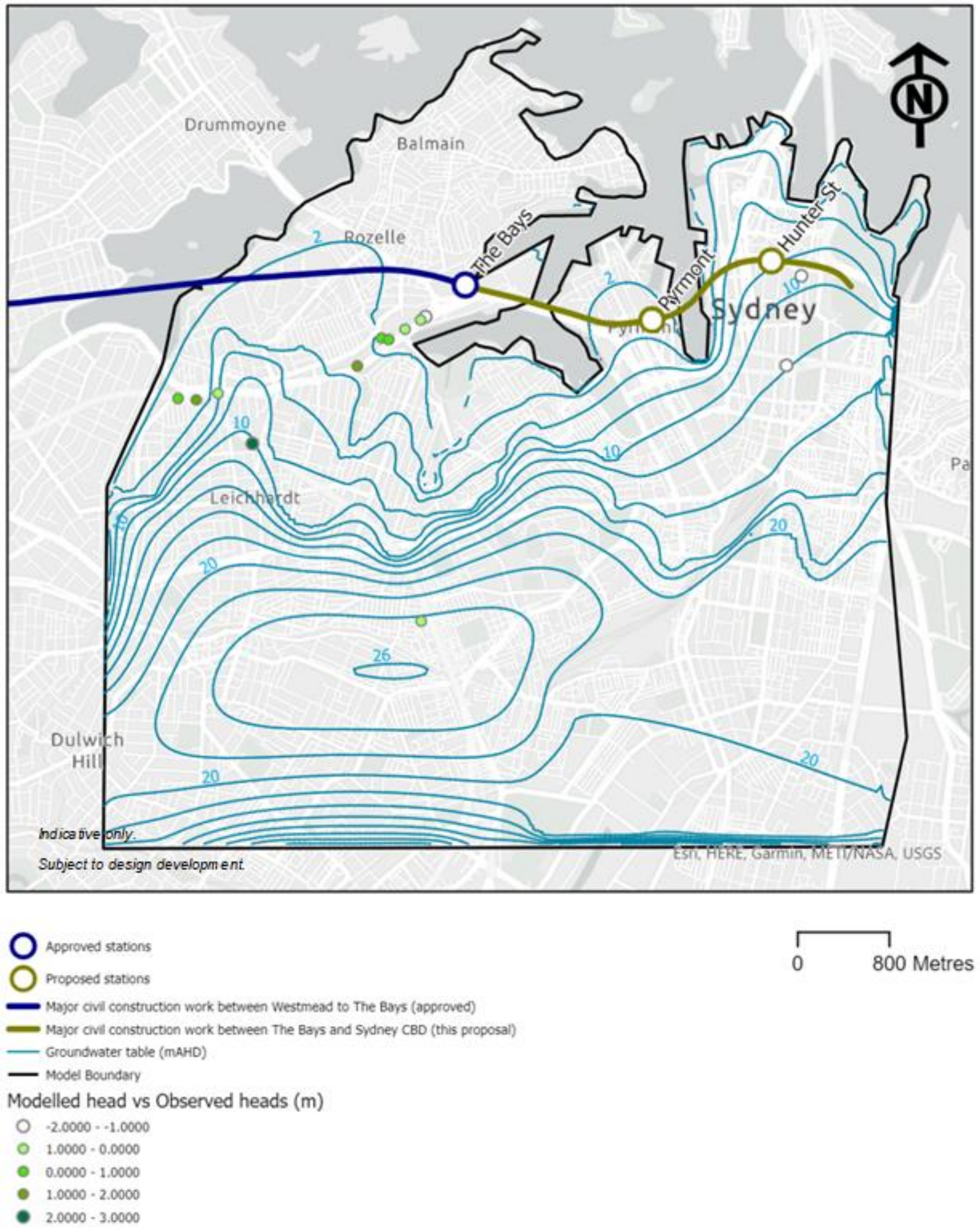

Figure 5-2: Steady state calibration, pre-construction groundwater table

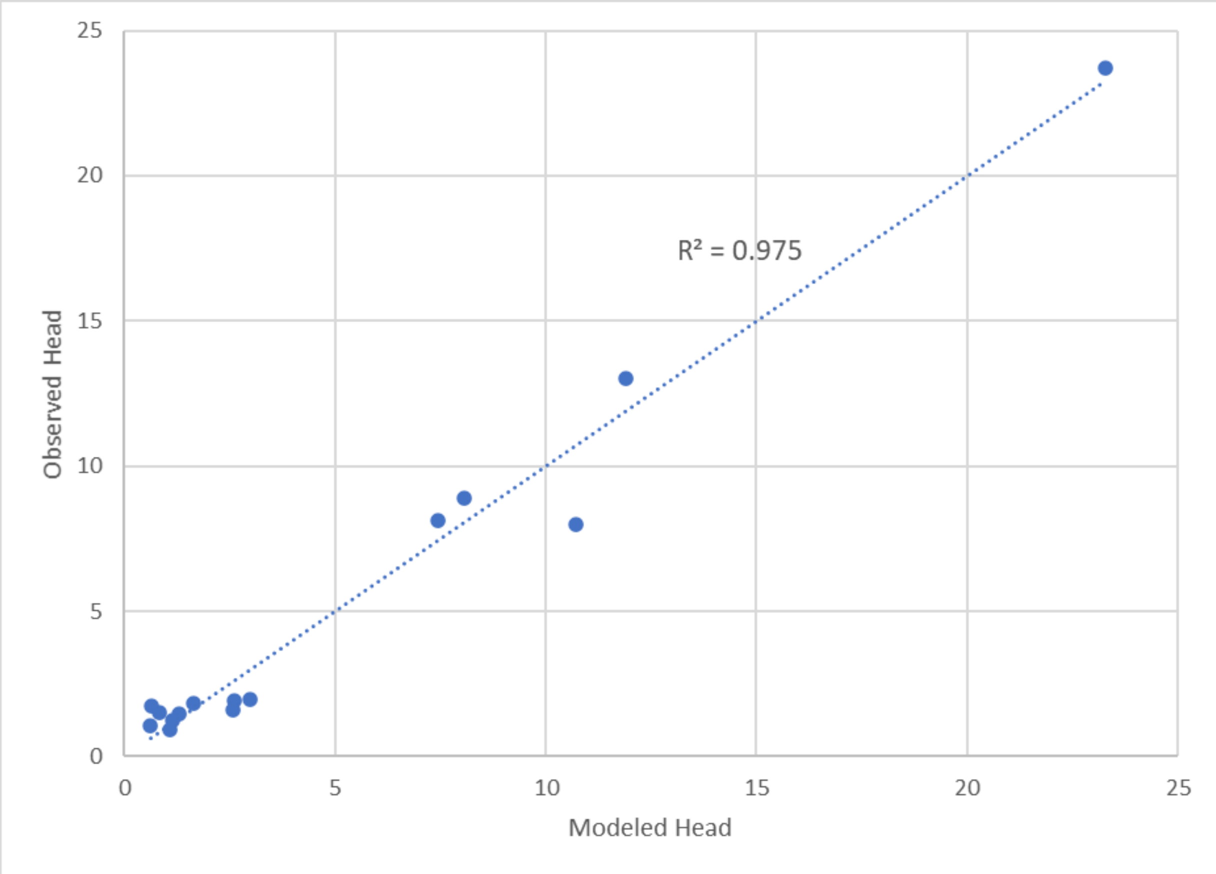

Figure 5-3: Modelled vs observed groundwater heads (mAHD)

Table 5-3: Modelled and observed groundwater heads (mAHD) at construction sites

Construction site	Observed head (mAHD)*	Modelled Head (mAHD)
The Bays	0.8 (SMW_BH066&067)	0.02
Pyrmont	*-2.4 (SMW_BN052)	3
Sydney CBD	2.9 (SMW_ENV101) to *-5.5 (SMW_ENV100)	7.5

*Note: *Observed head considered un-representative and ignored for calibration. The elevations are below sea level or lower than expected. This may be due to measurement errors or drawdown caused by drainage towards basements of surrounding buildings. Ignoring these values facilitates a conservative modelling approach.*

5.3.1 Assumptions

The groundwater management approach for both station complexes is provided in Table 5-4 and the following assumptions have been made with respect to the modelling:

- The modelling undertaken is preliminary for the purpose of initial impact assessment. The results provided are considered suitable for the intended purpose, however ongoing investigations may indicate different conditions and modelling should be reassessed

- The current model is considered to meet the requirements of Class 1 which allow for poor data distribution without time series and transient prediction based on the steady state calibration
- Station caverns and service shafts (station complex) have been assumed to be open and drained for two years during construction
- Inflows to the station complex have been estimated assuming "instantaneous excavation" to the design level and at 6, 12 and 24 months post excavation
- The three-dimensional Analytical Element Model AnAqSim (Analytical Aquifer Simulator) has been used to simulate the groundwater system and estimate drawdown and inflows both under steady state and transient conditions
- Inflows and drawdown during excavation have been modelled transiently using the calibrated steady state model, the transient model has not been calibrated against transient (time series) data
- Sensitivity analysis has been undertaken using steady state models as each variation in parameter essentially means the model is not calibrated and will not converge transiently
- The groundwater modelling is preliminary, based on limited hydro-geological information and assumptions have been made where information is not available. Additional groundwater modelling should be undertaken at later stages of the proposal when more site-specific information is available
- Site specific information such as lugeon packer test data has been assessed along with published aquifer properties values and existing modelling undertaken for projects in the vicinity. The actual values used in the calibrated model may differ but are within acceptable ranges
- The influence of climate change on long-term rainfall recharge is not expected to cause significantly different impacts than those predicted in the model. The former NSW Office of Environment and Heritage (2019c) NSW Climate Change projections for 2060 to 2079 predict increased rainfall in the Sydney region. Increased rainfall may increase recharge, which could result in reduced groundwater drawdown. However, climate change will also increase evapotranspiration reducing the potential recharge. The groundwater drawdowns predicted here are therefore considered reasonable under these predicted climate change (rainfall) scenarios
- Rock in the vicinity of water-bearing geological features such as faults, dykes and joint swarms may have relatively high hydraulic conductivity compared to the bulk rock. Identification of such features is assumed to be carried out and significant water-bearing features would be grouted prior to excavation, to reduce the potential for relatively high groundwater inflows during construction
- AnAqSim does not allow elements being modelled to partially penetrate model layers. This results in some elements (station caverns) being taller than the design. However, the base of all elements is correct with respect to their elevation and therefore the estimated inflows and resulting drawdown is considered reasonable for preliminary model estimates.

Table 5-4: Groundwater management approach and assumptions

Construction site	Excavation Type	Construction*	Design**
The Bays Crossover Cavern	Mined	Drained	Tanked (rock)
Pyrmont Station	Mined cavern	Drained	Tanked (rock)
Pyrmont service shafts	Shaft (top down)	Drained	Drained (soil and rock)
Hunter Street Station (Sydney CBD)	Mined cavern	Drained	Tanked (rock)
Hunter Street service shafts	Shaft (top down)	Drained	Drained (soil and rock)
Running Tunnels	TBM	Tanked[1]	Tanked

*Note: *Running tunnels will be lined within twenty four hours of excavation and any identified water bearing features will be treated prior to excavation.*

*Note: **The shafts are considered drained for hydrology design purpose only.*

5.4 Limitations

Information on ground and hydrogeological conditions is limited along the alignment and at station and services facilities. The level of characterisation of hydrogeological conditions and potential impacts are limited to the data available and the preliminary nature of the proposal design. Reasonable assumptions have been made where conditions are limited or unknown, based on known conditions in similar hydrogeological environments, with model parameter values adopted based on those reported in literature and associated with nearby projects with models.

Impact assessment conclusions may differ from those presented in this Technical Paper if conditions are found to be different from those modelled and assumed. This impact assessment is adequate to assess general environmental impacts and provide recommendations for monitoring and mitigation. These would require refinement as this proposal passes through the detailed design stage and validation is undertaken through the construction stage of the proposal.

There is some uncertainty regarding the potential baseflow loss to waterways due to Pyrmont and Hunter Street station (Sydney CBD) complex excavations since data on the ground conditions (stratigraphy) and groundwater levels are limited or not available. While it is not possible to assess existing groundwater baseflow with confidence, and by extension, quantification of the impact of this proposal station and services shaft excavations on baseflow. The assessment conducted is considered conservative as it does not include existing drawdown due to basements and tunnels and does not indicate impacts to groundwater baseflow to surface features. Further review of the potential change in baseflow due to this proposal station and services facility excavations would be completed based on the findings of additional site investigation that would be carried out during detailed design.

5.5 Excavation and groundwater management strategy

This proposal would involve excavation of the tunnels, stations and shafts for Sydney Metro West between The Bays and Hunter Street. The approach for groundwater management and design assumptions include:

- Station complexes (cavern and shafts) are drained during construction
- Long term steady state assumes the station caverns are tanked and the shafts drained, (Note the assumptions may be revised as planning progresses, the long term groundwater management will be included in future reports for the operational stage of the proposal).

Drawdown of the groundwater table is anticipated to occur during the construction and operational phase of the proposal. Inflows to station caverns, shafts and tunnels during construction will be unrestricted (unless required to be controlled to meet PS requirements) until the concrete lining is applied and therefore construction related drawdown impacts are anticipated to be larger than operational. The construction period is assumed to be two years from the time excavations begin to sealing of the station caverns. It is anticipated groundwater levels surrounding station caverns will partially recover post construction as they will revert to being tanked. However, shafts may remain drained and will therefore continue to support a cone of depression surrounding the construction site.

5.6 Groundwater modelling results summary

This proposal excavation program indicates construction will be staged as follows:

- The service shafts will be excavated first and be completed in approximately 12 months
- The caverns will commence excavation at approximately month 12 and complete excavation by month 24 when they will be sealed.

For modelling purposes, the volumetric groundwater take for each excavation is provided for six months, one year, and two years assuming all excavations are at design level to address the requirements of the NSW Aquifer Interference Policy and the Water Sharing Plan.

Inflows to the excavations are expected to decrease over time as the resulting cone of depression (drawdown) increases and approaches steady state. The inflows and drawdown have been assessed assuming instantaneous excavation. Under this approach the maximum drawdown occurs at day one and is equivalent to the invert of the excavation. The area of drawdown (size of the cone of depression) will increase from this point to year two where it will be at its largest.

Given that this proposal excavations would be carried out over a period of approximately two years, and the groundwater modelling assumes the excavations are instantaneous, the predicted groundwater level drawdown at two years after excavation therefore represents a conservative (greater) estimate of the likely groundwater level drawdown due to this proposal.

5.7 Pyrmont Station – construction phase

The Pyrmont Station construction sites would require the excavation of two service shafts, one to the east and one to the west of the cavern.

5.7.1 Groundwater levels

The estimated groundwater level drawdown from the preliminary transient model associated with construction at two years post excavation is shown on Figure 5-4. The water level adjacent to the excavations is the invert of the excavation at approximately -28 mAHD. Based on an initial preconstruction water level of three mAHD the maximum drawdown is approximately 31 metres in the immediate vicinity of the excavations. The cone of depression is very steep adjacent the excavation during construction. Interpreted contour intervals shown are not consistent due to the scale provided and vary from five metres to one metre. Figure 5-4 shows the interpreted groundwater drawdown based on model outputs for layers one, two, three and four at two years post excavation.

5.7.2 Groundwater inflows and local flow regime

The estimated groundwater inflow from the preliminary transient model associated with construction at various stages of excavation is shown in Table 5-4 for groundwater model layers one to four at six months, one year and two years respectively and are 0.70, 0.54, and 0.43 litres per second (Table 5-5). Peak inflows will be experienced on reaching the full depth and may be up to 1.5 L/sec. The annual take is estimated to be 26 megalitres in the first year and approximately 15 megalitres in the second year.

Most of the groundwater inflow is sourced (taken) from the rock aquifer in which the station is to be located. The overlying soil horizons are largely capped by paved surfaces intersected by large buildings which are assumed to have underlying basements.

The groundwater flow regime in the vicinity of the construction site is expected to change due to excavation. Under current conditions groundwater is interpreted to flow away from the construction site towards the harbor to the east, north and west. With this proposal construction, the station complex excavation would act as a groundwater sink, causing groundwater to flow towards the excavation effectively reversing the local flow.

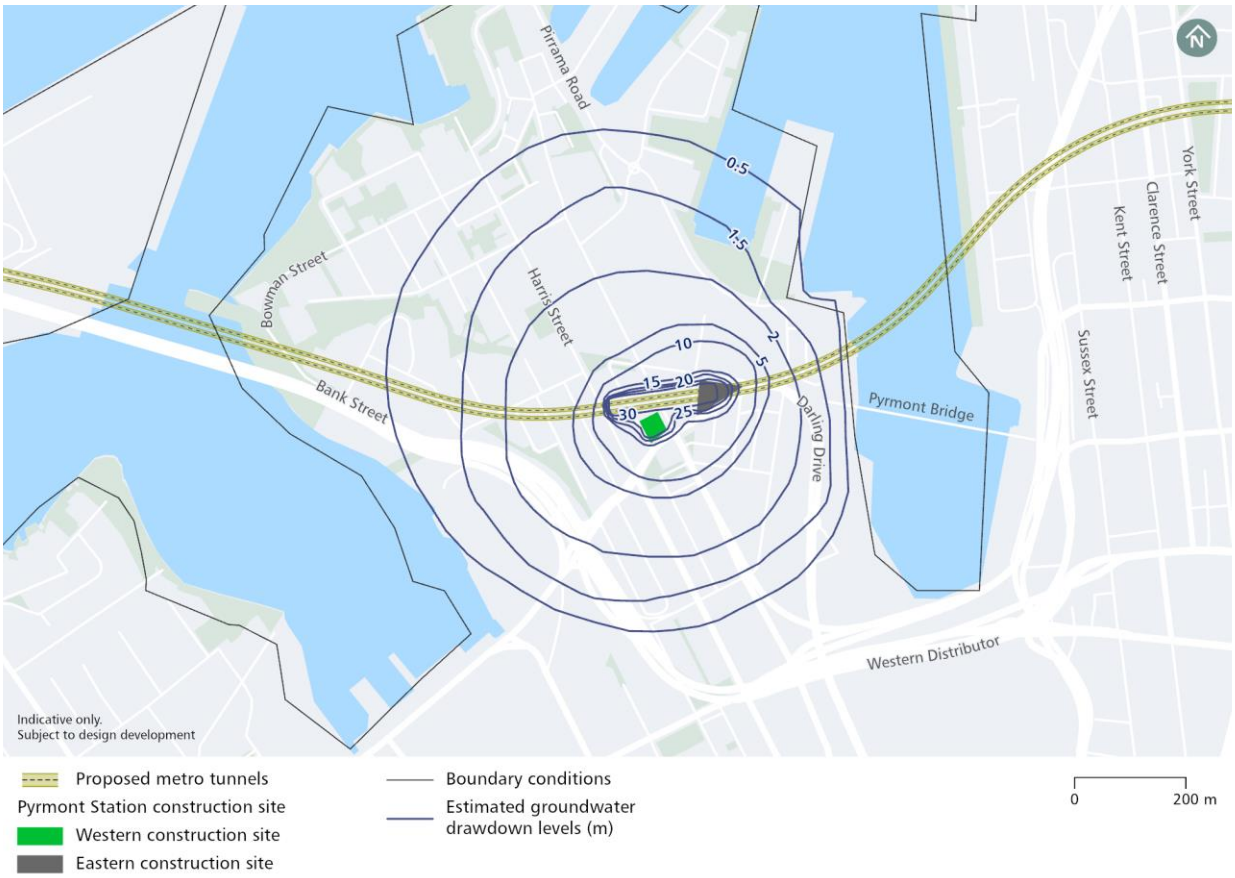

Figure 5-4: Estimated drawdown after two years due to proposal excavation – Pyrmont Station

Table 5-5: Modelled station element inflows for 6months, year 1 and 2 of construction – Pyrmont Station construction site

Element	Inflow 6 months	Inflow Year 1	Inflow Year 2
	L/sec (ML)	L/sec (ML)	L/sec (ML)
Pyrmont Station	0.18	0.15	0.12
Pyrmont Station Western Shaft	0.33	0.24	0.17
Pyrmont Station Eastern Shaft	0.19	0.15	0.13
Total	0.70 (16.2)	0.54 (26)	0.43 (15)

5.7.3 Groundwater recharge

Groundwater recharge to the Pyrmont area is already highly altered from the natural state. The land surface is now mainly impervious restricting the potential for infiltration of rainfall or surface water to the aquifer below, which would recharge the groundwater system. Reduced rainfall infiltration may be off set by artificial recharge via leaking pipes and irrigation of open spaces.

The surface within the proposed construction site is currently mainly impervious. This proposal is likely to increase the proportion of impervious areas through the site establishment and excavation which could reduce recharge rates within the footprint of the construction site. However, this area is small relative to the local catchment area, and the net impact on regional recharge due to Pyrmont Station construction site is not likely to be significant.

5.7.4 Groundwater quality

The station cavern and shafts are expected to act as a groundwater sink, resulting in surrounding groundwater in the Hawkesbury Sandstone to flow towards the excavations. This groundwater movement has the potential to cause groundwater to flow towards the excavation that is of a different quality than existing background conditions.

There is potential for groundwater both within, and adjacent to, the construction site footprint to be impacted by hydrocarbons (TRH, BTEX, PAH) and VOC (Jacobs, 2020b).

There is potential for groundwater impacts associated with the ingress of contaminated groundwater into excavations and the management of dewatering during the construction of the station caverns. Any potentially contaminated groundwater within the extent of groundwater level drawdown would migrate towards the station excavation. Contaminated groundwater seeping into the excavation could pose a potential exposure risk to site users/workers and adjacent site users and could reduce the beneficial use of the aquifer. Groundwater inflow would be collected and treated during construction.

The Pyrmont Station construction sites lie at the top of the ridge on the Pyrmont peninsula. The ridge essentially forms the groundwater divide with flow outward towards the harbour to the east, north and west. During construction (and operation) of the station the groundwater flow direction will be reversed, and the cone of depression is expected to reach the harbour

250 metres to the east. Groundwater at depth below the peninsula is expected to be saline and dewatering is likely to induce saline intrusion.

5.7.5 Acid sulfate soils

Potential acid sulfate soils are identified along the harbour foreshore associated with marine sediments. If the equilibrium of soil water flux within these soils is disturbed in a manner that results in a greater extent of wetting and drying with increased exposure to oxygen in areas not normally subjected to fluctuations between saturated and unsaturated conditions, then sulphuric acid will be laeched out of the soil more rapidly and could pose a pollution risk. The soils at the edge of the harbour have been exposed to centuaries of tidal flux and periods of extreme flooding. To disturb this natural flux sufficiently to accelerate the current rates of very gradual naural leaching, a significant disruption of the natural range of soil water flux would need to occur. The acid sulfate soils are, however, in constant contact with the harbour which will provide a constant fluctucting recharge source and therefore prop up (sustain) the natural variations in the groundwater levels around the edge of the harbour.

A drawdown cone will develop around the station as water drains into it. The gradient of the cone will be steepest near to the station but it will flatten exponentially as it approaches the edge of the harbour and will not likely result in an alteration to the current soil water flux at the edge of the harbour.

Modelling indicates drawdown of the water table may occur at the forshore, (Figure 5.4). More detailed modelling of the interactions between fresh and saline water at the edge of the harbour (Figure 5.6, discussed later) shows that a near horizontal profile of the drawdown cone will develop closer to the edge of the harbour. The continuous direct hydraulic contact between acid sulfate soils and the harbour is therefore not anticipated to be impacted on by drawdown at the edge of the harbour. Groundwater drawdown impacts to acid sulfatephate soils are therefore not expected, however monitoring and further investigation will be required at the detailed design stage.

5.7.6 Groundwater dependent ecosystems

There are no mapped groundwater dependent ecosystems in the area of potential groundwater drawdown associated with the construction of Pyrmont Station.

5.7.7 Beneficial use

There are no registered groundwater bores with a beneficial use within the area of potential groundwater drawdown associated with the construction of Pyrmont Station.

5.7.8 Surface water - groundwater interactions

There are no surface freshwater bodies or creeks within the area of potential drawdown associated with the construction of Pyrmont Station or in the vacinity of the construction site. There are creeks located south of the construction site around 600 metres to 800 metres away at the head of Cockle Bay and Blackwattle Bay respectively. These creeks are generally concrete lined channels and serve mainly as stormwater discharge. It is not known if they have a groundwater discharge component, however, they fall outside the area of predicted drawdown.

5.7.9 Saltwater intrusion

Groundwater drawdown contours (Figure 5-4) indicate the cone of depression will intersect the harbour during the two year construction period. An assessment of the potential saltwater intrusion was undertaken in transient model. The potential for migration of the interface was assessed along a line running through Pyrmont cavern and the eastern shaft east to the harbour 250 metres away. The model ran successfully for approximately 600 days (1.7 years).

Transient simulation in AnAqSim generates discontinuous interfaces at layer boundaries because of the Dupuit approximation within individual layers. Because interface positions are computed from aquifer heads and the Dupuit approximation is made in each layer, vertical flow causes discontinuities in the interface as layer boundaries are crossed. This results in the interface domains being inaccurate as it is assumed that the salt water has a hydrostatic distribution of pressure on the interface. In most transient situations, the salt water is moving, and when that movement has a vertical component, the hydrostatic pressure assumption is violated. However, the simulated interface surfaces are considered to provide a useful indication of the potential interface geometry. Based on the model output the interpreted interface is provided on Figure 5-5.

The potential saltwater interface rise may be as much as 40 metres for each one metre reduction in the freshwater head. At the station the preconstruction interface is assumed to be approximately -100 metres AHD based on a 2.5 metres AHD water table. The drawdown surrounding the station excavations is approximately 29 metres and up to 0.5 metres adjacent the coast. The modelling indicated the interface at 600 days (less than two years) had reached the excavations.

Therefore, under a drained construction scenario Pyrmont Station is likely to induce up-coning of the saline water interface to the shafts and cavern after two years (Figure 5-5).

Horizontal migration of the interface is likely to take much longer.

The estimated inflows to the excavations during construction are relatively small (total for station <0.7 L/sec) even so measures to limit construction inflows are likely to be required to limit potential up-coning. In addition, the service shafts may need to be designed as tanked in the long term or the shaft lining and equipment designed to deal with saline water. Additional modelling is likely required to assess the allowable inflow limits for construction purposes.

Table 5-6: Allowable and modelled long term steady state inflows – Pyrmont Station construction Site

Element	Allowable inflow (L/sec)	Modelled inflow (L/sec)	Modelled inflow (ML/year)
Pyrmont Station	0.01 to 0.025	0.019	0.6
Pyrmont Station Western Shaft	3.5	0.14	4.4
Pyrmont Station Eastern Shaft	4.0	0.11	3.5

Additional monitoring will be needed to support the construction stage and provide baseline information for the operational stage. This is discussed further in section 6.

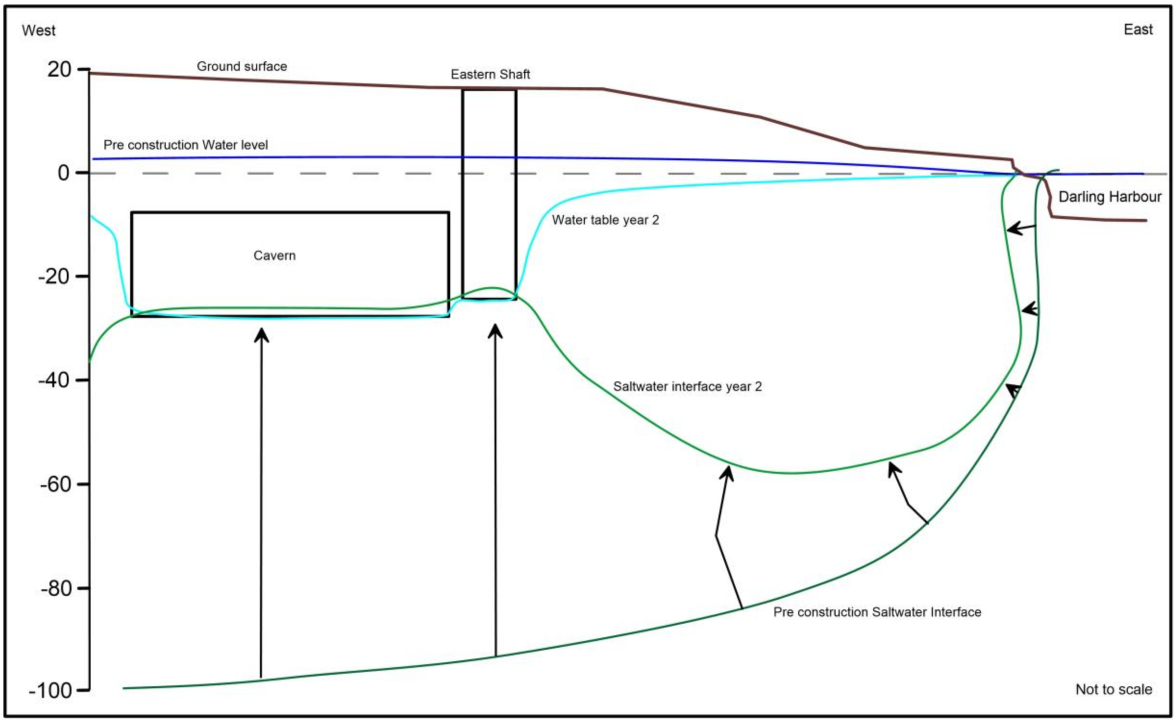

Figure 5-5: Interpreted saltwater interface migration after 2 years of construction

5.8 Hunter Street Station (Sydney CBD) – construction phase

The Hunter Street Station (Sydney CBD) construction site would require the excavation of the cavern and two service shafts, one to the east and one to the west of the cavern.

5.8.1 Groundwater levels

The estimated groundwater level drawdown from the preliminary transient model associated with construction at two years of excavation is shown on Figure 5-6. The water level adjacent to the excavation is assumed to be the invert of the excavation at approximately -22 meters AHD. Based on a (conservative) pre-construction water level of 7.5 metres AHD the maximum drawdown may be approximately 29 metres. The cone of depression adjacent the excavation is very steep Interpreted contour intervals shown are not consistent due to the scale provided.

5.8.2 Groundwater inflows and local flow regime

The estimated groundwater inflow from the preliminary transient model associated with construction at various stages of excavation is shown in Table 5-7 for groundwater model layers one to four at six months, one year, and two years respectively and are 0.95, 0.72, and 0.6 litres per second. The groundwater inflow is sourced (taken) from the fractured rock aquifer and is estimated to be up to 35.3 megalitres in the first year, and 18.2 megalitres in the second year.

The groundwater flow regime in the vicinity of the construction site is expected to change due to excavation. Under current conditions, groundwater is interpreted to flow away from the construction site towards the harbor to the north-east, north and north-west. With construction, the station complex excavation would act as a groundwater sink, causing groundwater to flow towards the excavation effectively reversing the flow to the north and west. It should be noted that the preconstruction water table is considered conservative (higher elevation) due to a lack of site-specific water level data in the highly impacted CBD area, interpreted drawdown contours are therefore considered to overestimate the magnitude and extent of the likely drawdown.

5.8.3 Groundwater recharge

Groundwater recharge to the CBD area is already highly altered from the natural state. The land surface is now mainly impervious restricting the potential for infiltration of rainfall or surface water to the aquifer below, which would recharge the groundwater system. Reduced rainfall infiltration may be offset by artificial recharge via leaking pipes and irrigation of open spaces.

The surface within the proposed construction site is currently mainly impervious. There may be increased proportion of impervious areas through the site establishment and excavation which could reduce recharge rates within the footprint of the construction site. However, this area is small relative to the local catchment area, and the net impact on regional recharge due to Hunter Street Station (Sydney CBD) construction is not likely to be significant. Furthermore any recharge falling on the construction site and entering the shafts will be captured and removed during construction.

5.8.4 Groundwater quality

The station caverns and shafts are expected to act as a groundwater sink, resulting in surrounding groundwater in the Hawkesbury Sandstone to flow towards the excavations. This groundwater movement has the potential to cause groundwater to flow towards the excavation that is of a different quality than existing background conditions.

There is potential for groundwater both within, and adjacent to, the construction site footprint to be impacted by hydrocarbons (TRH, BTEX, PAH) and VOC.

There is potential for groundwater impact associated with the ingress of contaminated groundwater into excavations and the management of dewatering during the construction of the station caverns. Any potentially contaminated groundwater within the extent of groundwater level drawdown would migrate towards the station excavation. Contaminated groundwater seeping into the excavation could pose a potential exposure risk to site users/workers and adjacent site users and could reduce the beneficial use of the aquifer. Groundwater inflow would be collected and treated during construction.

Hunter Street Station (Sydney CBD) construction site lies in a small depression associated with the Tank Stream, which runs roughly down the centre of the CBD sub parrallel to Pitt Street. The groundwater divide sits to the east just east of Macquarie Street. Groundwater flow in the vacinity of the station is in a west north west direction from the high ground to the east. During construction (and operation) of the station, the local groundwater flow direction wion periodill be reversed to the north and west and the cone of depression (0.5 metres drawdown contour) is expected to reach the harbour 500 metres to the north at Sydney Cove. Groundwater at depth below the peninsula is expected to be saline and dewatering may induce saline intrusion.

The modelling approach used in this technical paper is conservative. Numerous buildings with drained basements exist between the station and the harbour. This technical paper presents a worse case scenario for purposes of estimating inflow to the proposed station and therefore excluded the impacts of groundwater draining towards the basements of existing buildings. It is considered unlikely that an intrusion of saline water would reach the Hunter Street Station due to this drainage. Although considered to be unlikely, further modelling would be required to ascertain whether the intrusion would reach the station during the operation phase.

5.8.5 Acid sulfate soils

Potential acid sulfate soils are identified along the Sydney Harbour foreshore. The harbour will provide a continuous recharge source and is therefore considered to prop up groundwater levels around the edge of the harbour. Groundwater drawdown impacts to acid sulfate soils is therefore considered a low risk. Furthermore the highly disturbed nature of the groundwater system in the CBD area is likely to have already resulted in impacts reducing the potential for impacts associated with this proposal.

With respect to other soils within the drawdown zone, most are highly disturbed and capped by paved areas or buildings. For parks and gardens, the soil salinity and other soil water quality are unlikely to be affected by the drawdown as groundwater fluctuations and drawdown will be below the soil horizons. Contaminated water will be drawn downwards towards the station.

5.8.6 Groundwater dependent ecosystems

There are no mapped groundwater dependent ecosystems in the area of potential groundwater drawdown associated with the construction (and operation) of Hunter Street Station (Sydney CBD).

5.8.7 Beneficial use

There are no registered groundwater bores with a beneficial use within the area of potential groundwater drawdown associated with the construction (and operation) of Hunter Street Station (Sydney CBD).

5.8.8 Surface water - groundwater interactions

There are no surface freshwater bodies or creeks within the area of potential drawdown associated with the construction (and operation) of Hunter Street Station (Sydney CBD). The station would be located within the CBD a highly altered groundwater environment.

There are creeks located south west of the construction site around 1,000 metres away at the head of Cockle Bay. This creek is generally a concrete lined channel and serve mainly as stormwater discharge. It is not known if they have a groundwater discharge component, however, it falls outside the area of predicted drawdown.

The baseline groundwater monitoring needs to be evaluated and amended if necessary so that it can be used in future to compare piezometric water levels to the proposaled draw cone as the construction progressed. Appropriate mitigation would be need to be implemented should the water levels and water quality triggers indicate that a response is required (discussed later in section 6).

Figure 5-6: Estimated drawdown after 2 years due to excavation – Hunter Street Station (Sydney CBD)

Table 5-7: Modelled station complex inflows for year 1 and 2 of construction – Hunter Street Station (Sydney CBD) construction sites

Element	Inflow 6 months	Inflow Year 1	Inflow Year 2
	L/sec (ML)	L/sec (ML)	L/sec (ML)
Hunter Street cavern	0.21	0.17	0.16
Hunter Street Western Shaft	0.32	0.23	0.18
Hunter Street Eastern Shaft	0.42	0.32	0.26
Total	0.95 (22.3)	0.72 (35.3)	0.6 (18.2)

Additional monitoring will be needed to support the construction stage and provide baseline information for the operational stage. This is discussed further in section 6.

5.9 Sensitivity analysis

A sensitivity analysis was undertaken on the base case model to understand the potential impacts of variable ground conditions on predicted inflows at Pyrmont and Hunter Street Stations (Sydney CBD). The variables assessed were the horizontal permeability, which is linked to the vertical permeability in the model and rainfall recharge. Six scenarios were run as per Table 5-8. The results are summarised in Table 5-9 for scenarios 1 to 4 and Table 5-10 for scenarios five and six and the results plotted on Figure 5-7 and Figure 5-8 respectively.

5.9.1 Discussion

The values chosen for sensitivity assessment were based on knowledge that the permeability may range over three orders of magnitude for the Hawkesbury Sandstone indicating more than an order of magnitude increase is reasonably possible. Recharge changes are considered less likely as rainfall is not likely to halve or double nor is the area available for recharge (open space) likely to double.

The sensitivity assessment addresses the impact of varying hydraulic conductivity and recharge. The results indicate that halving the permeability in Figure 5-7 has little impact on the predicted inflows as they are already estimated to be small. Increasing the permeability by one or two orders of magnitude may increase the inflows by between two and ten times. However, inflows are still considered small relative to the size and depth of the excavations as the bulk rock permeability is still low.

Halving the recharge in Figure 5-8 has limited impact on the inflows while doubling the recharge may result in a negligible increase to an approximate doubling of the inflow to certain elements.

Based on the analysis lower permeability and or recharge have a limited impact on predicted inflows while increasing permeability and or recharge may increase inflows. The amount of inflow increase is in the range of two to four times for one order of magnitude increase and between 6 and 10 times for a two order of magnitude increase in permeability indicating moderate sensitivity. Doubling the recharge has a 1.1 to 2 times increase in inflow indicating low sensitivity.

While an increase in permeability would be expected to increase the inflow the magnitude of increase indicated by the sensitivity analysis indicates that under the hydrogeological conditions (low permeability) at each station permeability of the rock mass would need to increase by more than two orders of magnitude to significantly increase inflows to the excavations to a level where ground improvement would be required.

Table 5-8: Sensitivity scenarios

Sensitivity Scenario	Horizontal hydraulic conductivity	Vertical hydraulic conductivity	Rainfall Recharge
1	0.5	0.5	As per base case
2	5	5	As per base case
3	10	10	As per base case
4	100	100	As per base case

Sensitivity Scenario	Horizontal hydraulic conductivity	Vertical hydraulic conductivity	Rainfall Recharge
5	As per base case	As per base case	0.5
6	As per base case	As per base case	2

Table 5-9: Inflow to proposal elements for permeability sensitivity assessment

Element / Multiplier	Scenario (L/sec)				
	1	base case	2	3	4
Pyrmont station	0.010	0.02	0.070	0.124	0.938
Pyrmont shaft west	0.054	0.14	0.479	0.597	1.712
Pyrmont shaft east	0.050	0.11	0.642	0.961	1.790
CBD station	0.013	0.024	0.044	0.069	0.616
CBD shaft west	0.114	0.15	0.449	0.699	1.823
CBD shaft east	0.161	0.23	0.568	0.834	1.862

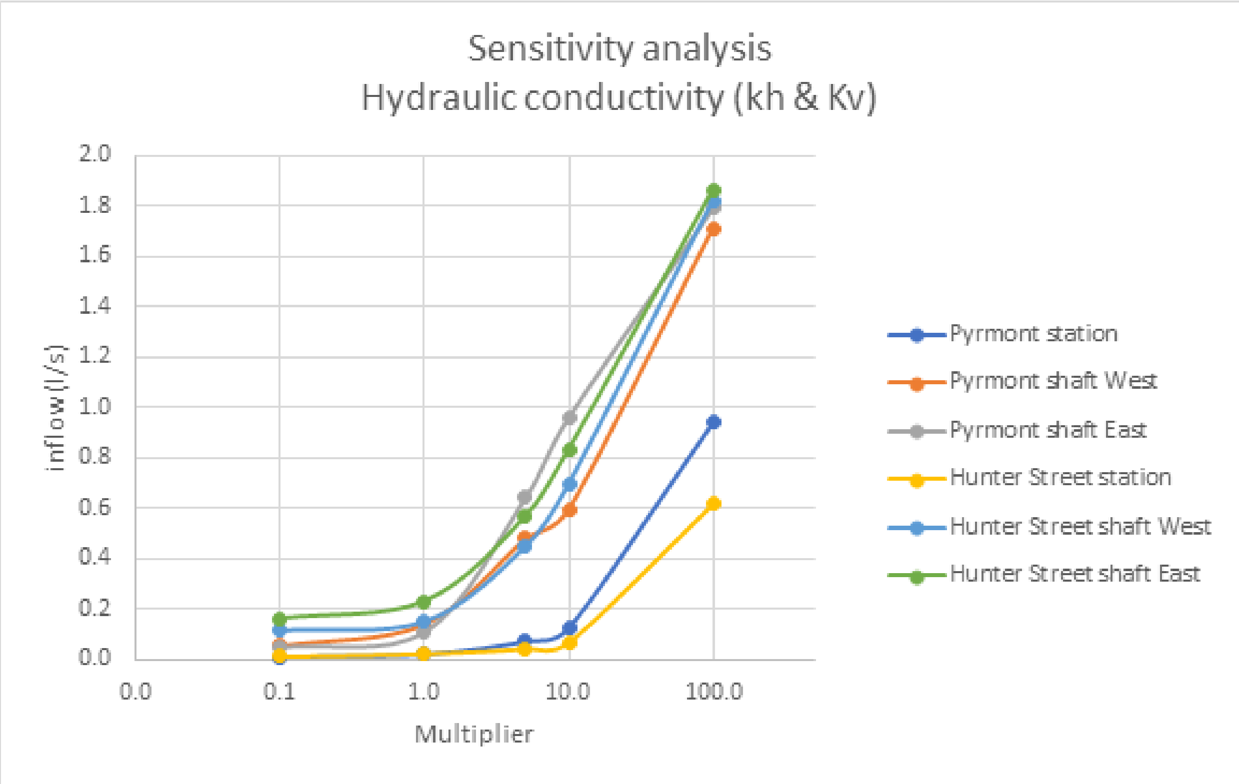

Figure 5-7: Hydraulic conductivity sensitivity analysis results summary

Table 5-10: Inflow to proposal elements for recharge sensitivity assessment

Element / Multiplier	0.5 (Scenario 5)	1 (Base case)	2 (Scenario 6)
Pyrmont station	0.015	0.02	0.027
Pyrmont shaft west	0.129	0.14	0.190
Pyrmont shaft east	0.008	0.11	0.233
CBD station	0.016	0.02	0.027
CBD shaft west	0.131	0.15	0.295
CBD shaft east	0.178	0.230	0.398

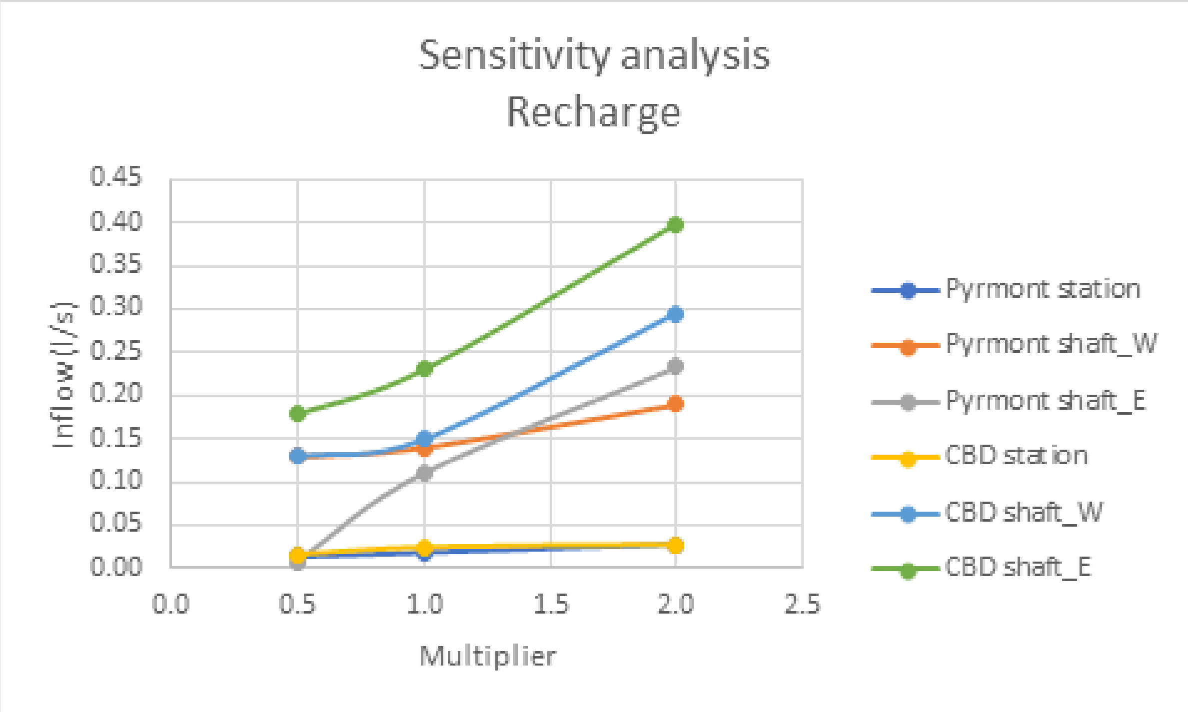

Figure 5-8: Recharge sensitivity analysis results summary

5.10 Running tunnels and cross over cavern

The mainline running tunnels will be constructed using a Tunnel Boring Machine (TBM) predominantly through Hawkesbury Sandstone and will pass beneath Johnstone Bay between the Bays tunnel launch and support site and Pyrmont Station and Cockle Bay between the proposed Pyrmont Station and Hunter Street Station (Sydney CBD) and include the stub tunnels east of Hunter Street Station. Tunnel construction would pass beneath the waterbodies described in Table 5-11.

Table 5-11 Depth of tunnelling and relevant waterbodies

Alignment section	Depth of tunnel (metres)	Waterbodies above tunnel alignment
Between The Bays tunnel launch and support site and Pyrmont Station construction sites	44-52	Johnstons Bay
Between Pyrmont Station construction sites and Hunter Street Station (Sydney CBD) construction sites	27-42	Cockle Bay

The TBM tunnels will be lined with pre-cast segmental linings as the tunnels progress. It is assumed that closed modes, Earth Pressure Balanced or Slurry Mode would be used under the bays and that open face mode may be used under land. Given the relatively short portions of tunnels under land and complexity of changing from open to closed modes, it is also assumed that one method is likely to be used for the entire tunnel length.

For assessment of potential inflows it is assumed open face mode is used. The inflow to the tunnel heading has been estimated with the following assumptions:

- The TBM advances 12 metres per day
- Each 12 metres advance is lined daily
- Inflow may only occur over the open 12 metres section of tunnel
- The tunnel is hydraulically connected to the water table (hydrostatic conditions)
- The head acting on the tunnel is assumed to be the interpreted water table along the alignment.

The formula provided by Goodman et al (1965) has been used and adjusted as per Heuer (1995) to assess inflows to the tunnels. The Goodman equation is as follows.

$$Q = 2\,\pi\,K \frac{h}{\ln(\frac{2\,.\,h}{r})}$$

where:

Q = tunnel inflow (m^3/day)

K = hydraulic conductivity (m/day), ranges from 0.001 to 0.1 m/day

h = distance between the centre of the tunnel and the groundwater table (m)

r = tunnel radius (m), assumed to be four metres

Heuer (2005) noted that the Goodman et al (1965) equation generally overstated tunnel inflows by a factor of up to eight and therefore proposed that the Goodman equation results be divided by eight where limited information exists.

5.10.1 Tunnel inflows

The potential inflow to the tunnel face has been estimated for the TBM tunnel using average conditions over a section. The estimated potential inflow ranges from 0.3 m^3/day and 40 m^3/day in Table 5-12. Inflows are assumed to be highest under the bays where it is interpreted structures are present and there is a direct hydraulic connection between the harbour, the alluvial sediments, and the sandstone.

The length of the tunnel (assuming only one at this stage and ignoring the stations) is 2,900 metres from the Bays tunnel launch and support site to Hunter Street Station (Sydney CBD). Assuming 12 metres per day advance rate one tunnel may be completed in under a year resulting in an approximate 960 m^3 (one megalitre) cumulative take at the face. The allowable long-term inflow is 2 ml/hr/m^2 of lining or about 0.03 L/sec/km of tunnel, which allows a potential annual inflow of up to 2.75 megalitres per tunnel.

Therefore, the potential groundwater inflow, over a two-year tunnel construction period (excavation and construction of twin tunnels) is the sum of the face inflows plus the allowable leakage to lined sections of the tunnels. The annual inflow during construction is estimated to be around 2.5 megalitres in year 1 (one megalitre face inflows + 50 per cent lining inflows) increasing to approximately six megalitres during year two (lining inflows from tunnel 1 + face inflows + 50 per cent lining from tunnel two). The annual inflow reduces to approximately 5.5 megalitres per year when both tunnels are lined.

5.10.2 Tunnel drawdown

Drawdown of the water table as a result of tunnel excavation is considered to be negligible due to; face inflows being short-term occurring over 24 hours, the harbour provides a continuous recharge source, and allowable tunnel inflows are very small at 0.03 L/sec/km. Transient modelling of tunnel inflows was not undertaken and steady state modelling (not included for this proposal) did not provide a discernible drawdown response to allowable tunnel inflows.

5.10.3 Crossover cavern inflows

The estimated inflow to the Bays crossover cavern is around 45 m^3/day or 16.4 megalitres assuming a 12-month construction period and the cavern is open for the entire time before sealing. The cavern would be mined progressively, and inflows will increase as the excavation is opened. Sealing of the cavern is assumed to occur progressively restricting the open area allowing inflows. In addition, it is assumed the construction contractor will identify water bearing features and undertake ground treatment to minimise inflows prior to excavation. The estimated inflows are therefore considered conservative.

Geological features may impact inflows, such as the Great Sydney Dyke (GSD) which is located at the western end of the cavern. Inflows as a result of intersecting the GSD are typically in the range of one litre per second (Dale, Rickwood, and Wong, 1997). Intersecting the GSD may increase the inflow to the cavern from around 45 m^3/day to 130 m^3/day. Inflows may also be persistent (not reduce over time) if the dyke is connected to the adjacent alluvium and harbour. Persistent long-term inflows associated with a discrete feature may also result in drawdown along the feature. However, it is anticipated this feature would be treated to limit inflows prior to excavation based on additional investigation at the detailed design stage. Drawdown of the water table as a result of excavation of the mined cavern has been assessed using the model in steady state mode. The drawdown ranged from negligible to less than two metres due to the proximity of White Bay providing a continuous recharge source. In addition, the construction will seal the cavern as it is excavated to meet allowable inflow criteria and it is assumed any identified permeable features will be treated prior to excavation.

Table 5-12: Estimated inflow to tunnel face and cumulative inflow over sections

Element	Chainage		Length (m)	Average Head above tunnel section (m)	Adopted Permeability (m/day)	Inflow to 12m face (m^3/day)	Inflow over length (m^3)
Tunnel	2640	2480	160	42	0.001	0.36	4.76
Tunnel (Harbour)	2480	2360	120	45	0.1	37.70	377.01
Tunnel	2360	2220	140	44	0.001	0.37	4.32
Tunnel	2220	1800	420	36.5	0.001	0.32	11.23
Tunnel	1800	1560	240	27	0.001	0.26	5.10
Tunnel	1320	1200	120	27.5	0.001	0.26	2.59
Tunnel	1200	1040	160	32.5	0.01	2.94	39.13
Tunnel	1040	820	220	37	0.01	3.24	59.41
Tunnel (Harbour)	820	680	140	40	0.1	34.41	401.48
Tunnel	680	500	180	36	0.01	3.17	47.60
Tunnel	500	200	300	27.5	0.001	0.26	6.47
Alignment length (including	stations)		2900	Cumulative	face inflow	(per tunnel)	960
			Cumulative	inflow (ML)	from (one)	tunnel face	0.96
			Allowable	inflow to	single lined	tunnel (ML/year)	2.75
		Cumulative	groundwater	take over two	year	construction period (ML)	8.5

Table 5-13: Estimated inflow to the Bays crossover cavern

Element	Chainage	Length (m)	Head above cavern (m)	Adopted Permeability (m/day)	Inflow to cavern (m^3/day)	Inflow over 1 year (ML)
Cross over cavern	2640-2900	260	32	0.002	45	16.35

5.11 Cumulative impacts

The NSW Government Cumulative Impact Assessment Guidelines for State Significant Projects, released July 2021, defines Cumulative impacts, also referred to as cumulative environmental effects or cumulative effects, as a result of incremental, sustained and combined effects of human action and natural variations over time and can be both positive and negative. They can be caused by the compounding effects of a single project or multiple projects in an area, and by the accumulation of effects from past, current and future activities as they arise (NSW Government Cumulative Impact Assessment Guidelines for State Significant Projects July 2021).

Potential cumulative groundwater impacts include:

- Overlapping of groundwater drawdown associated with the station and cavern excavation. This could potentially occur in areas where the drawdown extends to the adjacent excavation impact; for example, the station shafts and station cavern at Pyrmont and similarly at Hunter Street (CBD North) are likely to be excavated at the same time. The groundwater modelling for the construction stage of these stations therefore determined, as a worst case, the combined drawdown effects of simultaneous excavations of shafts and caverns
- Existing and proposed infrastructure with drained excavations/structures near excavations, including building excavations associated with the Rozelle Interchange (part of the WestConnex M4-M5 Link), the Western Harbour Tunnel, the Sydney Metro City & Southwest (Chatswood to Sydenham) project, the New Sydney Fish Market, the Cockle Bay Warf Mixed Use Development, 50-52/54 Phillip Street New Hotel/Residential Building Stage 1 and 111 &121 Castlereagh/65-77 Market Street, Sydney.

The groundwater assessment provided in the Environmental Impact Statement for the WestConnex M4-M5 Link project (WestConnex Delivery Authority, 2017), which includes the Rozelle Interchange, does not predict long term (steady state) groundwater level drawdown for the Rozelle Interchange that lies within the predicted zones of groundwater level drawdown for the proposal. Based on this, the Rozelle Interchange is not expected to contribute cumulative impacts to the proposal.

The Environmental Impact Statement for the Western Harbour Tunnel and Warringah Freeway Upgrade (Roads and Maritime Services, 2019) shows that the tunnels associated with this project lie to the west of The Bays Station tunnel launch and support site. Groundwater modelling results reported for this project indicate that it is likely to cause groundwater level drawdown in the vicinity of The Bays tunnel launch and support site. Based on the predicted groundwater level drawdown at the end of tunnel construction for the project, an additional groundwater level drawdown of up to three metres would be expected at The Bays tunnel launch and support site. This drawdown would be additive to the drawdown induced by the proposal. The potential impacts of this cumulative drawdown and their significance are not expected to differ from those predicted for the proposal alone.

The Sydney Metro City & Southwest (Chatswood to Sydenham) project has, amongst others, four stations running Northwards beneath the Sydney CBD. They include proposed new stations in the vicinity of Central Station, Pitt Street, Martin Place and Barangaroo. Of these Martin Place and Pitt Street are closest to the Hunter Street (CBD) Station which is at the beginning of the Sydney Trains Western Line towards Westmead. The Hunter Street Station would be located below the latter two stations and drawdown towards it will be sufficient to dominate the groundwater flow in the area. The drawdown projected for the Hunter Street Station cavern and shafts (Figure 5-6) would supersede the drawdown from the latter stations if constructed simultaneously. Compounding effects towards the outer edges of the drawdown cone would be unlikely to result in an additional drawdown amount of less than half a metre.

The compounding effects from the following developments are likely to be negligible for the following reasons:

- The groundwater levels below the New Sydney Fish Market will mostly be determined by water levels in the Harbour which is immediately adjacent to the Fish Market
- The groundwater levels below the Cockle Bay Warf Mixed Use Development will mostly be determined by water levels in Cockle Bay, which is immediately adjacent to the development.

The 50-52/54 Phillip Street New Hotel/Residential Building Stage 1 is within the Hunter Street estimated drawdown Figure 5-6, groundwater levels are likely to drop by up to three metres during the construction phase. This drawdown would be additive to the drawdown induced by the proposal. The potential impacts of this cumulative drawdown and their significance are not expected to differ from those predicted for the proposal alone.

The 111 &121 Castlereagh/65-77 Market Street, Sydney development is within the Hunter Street estimated drawdown Figure 5-6, groundwater levels are likely to drop by up to one and a half metres during the construction phase. This drawdown would be additive to the drawdown induced by the proposal. The potential impacts of this cumulative drawdown and their significance are not expected to differ from those predicted for the proposal alone.

The risk of cumulative impacts in The Bays tunnel launch and support site area due to construction of the cross over cavern is considered low as drawdown associated with the construction is assessed to be limited by the proximity of the harbour which forms a continuous recharge source. It is also assumed the cavern will be lined as its excavated (to meet the allowable inflow criteria of five L/m^2/day) and any identified permeable features would be treated prior to excavation. In addition, the cavern will be tanked in the long term and any drawdown is expected to recover post sealing. The Stage 1 Technical Paper 7 – Hydrogeology, indicates The Bays Station may "experience cumulative drawdown impacts in excess of 26 metres due to the Western Harbour Tunnel construction, however this was not expected to be significantly different to those predicted for the Stage 1 Bays Station excavation". The predicted 26 metres drawdown associated with the Stage 1 Bays Station is considered conservative and is expected to recover post construction as the station cavern will be tanked. Cumulative impacts will therefore be dependent on timing of Stage 1 excavations at The Bays tunnel launch and support site.

The risk of cumulative impacts in the Pyrmont area is considered medium to high. There is already a degree of impact in the area due to basement dewatering and the station cavern and shaft excavations are likely to increase any existing drawdown. The risk of cumulative impacts affecting sensitive receivers and beneficial use due to groundwater drawdown is considered low as there are no sensitive receivers in the area of impact.

The risk of cumulative impacts in the Hunter Street Station (Sydney CBD) area is considered medium. The area is already highly altered by numerous tunnels, basements and barriers, and the station is likely to add to the overall drawdown, however the estimated drawdown is considered conservative as pre-existing drawdown has not been accounted for. The degree of cumulative impacts is therefore assumed based on the interpreted groundwater conditions. The highly disturbed nature of the area and requires further assessment, such as mapping existing basement and infrastructure levels and inflows followed by modelling. However, there are a lack of sensitive receivers and beneficial use within the area of potential drawdown and therefore the impact is considered low.

The combined or cumulative impacts of groundwater drawdown will vary depending on the timing of the construction stages of each project. If one project is completed and the excavated areas are tanked before the next project starts, then the cumulative drawdown impacts will be less than for a situation where two or more excavations are undertaken simultaneously.

5.12 Water balance

A preliminary water balance assessment was carried out for the construction period. Water demand and rates of consumption will differ based on the final construction methodology. At this preliminary stage of construction planning, the following methodology and assumptions were considered for this proposal water balance:

- The water balance is for this proposal, as there are insufficient site-specific water demand / supply data to provide an individual water balance for each site
- Estimated water consumption for this proposal was based on consumption records for the construction of Sydney Metro North West, with consumption approximately scaled to the Sydney Metro West tunnel length and number of stations/facilities sites.
- Potable water demand would be sourced from Sydney Water (mains supply)
- Non-potable water uses would include activities such as dust suppression, plant wash-down and concrete batching
- There is potential for some of the non-potable demand during construction to be met by supply from groundwater inflows to excavations. Groundwater inflows to station excavations would reduce with time. Evaporative losses are also assumed. The proportion of groundwater that is assumed able to be used in construction is 50 per cent
- Of the potable water used, 30 per cent would be recycled to meet non-potable water demand
- The remaining water would be discharged to the stormwater network, watercourses or potentially to the sewerage network (under a trade waste agreement)
- This is a preliminary order of magnitude assessment to highlight potential water supply and demand issues. It is not intended to provide a detailed assessment; this will be required at the detailed design stage of the proposal and may differ from the information provided here.

There may be an opportunity for rainwater harvesting at some construction sites. This opportunity may be explored during detailed construction planning. The water balance for this proposal is provided in Table 5-14. Based on this water balance, water demand is likely to exceed water supply by up to 100 megalitres a year during construction.

It is likely the supply deficit may be bigger as tunnelling under the harbour is likely to induce saline water inflows which will not be able to be used for construction non potable supplies.

There is limited opportunity for other non-potable supplies, such as bore water at the station locations. Potable supplies are likely to be required to meet the construction demand.

The discharge volume for water not able to be recycled or reused (due to salinity or other contamination) is likely to be around 40 megalitres to 50 megalitres, comprising just over 45 per cent of the shortfall in supply.

Table 5-14: Construction water balance

Water Source / Activity	Type	ML/year
Demand		
Construction activities for Stations	Potable	10
	Non potable	30
Construction activities for Cross Over Cavern	Potable	5
	Non potable	20
Construction activities for tunnels	Potable	20
	Non potable	80
Total demand		165
Supply		
Groundwater inflow, stations and tunnels (50 per cent)	Non potable	19
Sydney Water supply (Demand)	Potable	35
Recycled potable water for non-potable use (30 per cent)	Non potable	11
Supply total		65
Difference		100

Surface water resources (including freshwater bodies and creeks) will not be accessed for water supply for the construction period and are therefore not included in the water balance. The water treatment and discharge methodology and locations are provided in Technical Paper 8 – Hydrology, Flooding and Water Quality. Not included in the above water balance is the water requirement for The Bays Station construction site to launch and support two tunnel boring machines. The quantities of water required for this location is however considered to be relatively small and some of the non-potable water can be harvested from groundwater seepage.

5.13 Groundwater instrumentation and monitoring

5.13.1 Aim of monitoring

A robust instrumentation and monitoring strategy acts as a mechanism for allowing measurement and recording of actual effects resulting from underground and above ground construction works for comparison against the predicted and acceptable effects.

Instrumentation and monitoring will also allow for the following:

- Construction to be carried out safely
- Verification and validation of design assumptions and intent
- Provide information about predicted behaviour of installed retention support systems during construction
- Provide information to allow consideration of adjustments to proposed retention supports and/or construction sequences/methods based upon a comparison of predicted against actual behaviour
- Enable appropriate contingency and remedial measures to be implemented in a timely and efficient manner.

The implementation of instrumentation and monitoring may also act as an early warning system in identifying critical construction aspects and forewarning where a performance review and adjustment of the works (design and construction) may be required to minimise and mitigate any potential impacts to existing properties and infrastructure or to workers, plant and temporary structures.

The instrumentation and monitoring approach will generally cover:

- Structures/elements requiring instrumentation and monitoring
- The type of instruments required
- Monitoring frequencies to be adopted
- Observed performance levels (i.e., 'trigger levels') with appropriate movement limits for each structure/element being monitored
- Proposed actions to be adopted for each observed performance zone
- Remedial action and risk contingency plans, where relevant and required
- Assist with the 'permit to tunnel' or 'permit to excavate' process during construction.

Detailed instrumentation and monitoring plans will need to be developed at later design stages. These plans should be of enough detail to allow for successful implementation and use during construction works.

There may also be a need to provide separate instrumentation and monitoring plans to cater for intended purposes, such as determining potential impacts to third-party infrastructure, building or utilities. The requirements within this plan are likely to differ to those required for monitoring construction performance.

5.13.2 Groundwater monitoring

The following forms of monitoring are likely required for all underground works which intersect the groundwater table:

- Tunnels, instantaneous and cumulative
- Station caverns and shafts, instantaneous and cumulative
- Groundwater level changes during construction:
  - Along running tunnels
  - Adjacent to shafts \ Station caverns
  - Near any identified sensitive receivers such as GDE's or registered beneficial use.

5.13.3 Monitoring frequency and trigger levels

The frequency of monitoring will vary to suit the nature of the construction activity being undertaken within the immediate area and the sensitivity of the element being monitored. Discrete monitoring should not be considered in isolation, but rather integrated with all available monitoring data.

The baseline monitoring phase allows for enough standard readings to be obtained to establish reference conditions prior to construction works encroaching towards the instrument location. This phase also allows for installed instruments to be tested under working conditions and ensure that they are working and calibrated correctly.

The groundwater monitoring frequency during actual construction works may vary depending on the nature of the element being monitored. An initial frequency will be determined to suit design and construction objectives. However, this frequency can be adjusted to suit progression of tunnelling for example, be increased for closer scrutiny of obtained results, or decreased if monitoring trends are stabilising and/or showing minimal movement. A continuous review of monitoring data is required so that an appropriate frequency can be adopted. Instrumentation and monitoring plans need to allow for this flexibility in monitoring.

Consideration should also be given as to when monitoring may cease. This will usually require justification that the design and construction objectives have been met, recorded movements are negligible or within predicted values, and/or approval has been sought from the relative authority to do so.

Movement limits (or otherwise known as 'trigger levels') need to be ascribed to each monitoring instrument based on the design expectations and maintaining appropriate levels of safety in relation to the works being undertaken. These movement limits corresponding to the assignment of 'Observed Performance Zones' are used to facilitate meaningful assessment of the response required during the development of construction activities.

Figure 5-9 shows an example of a three-level system typically employed for instrumentation and monitoring.

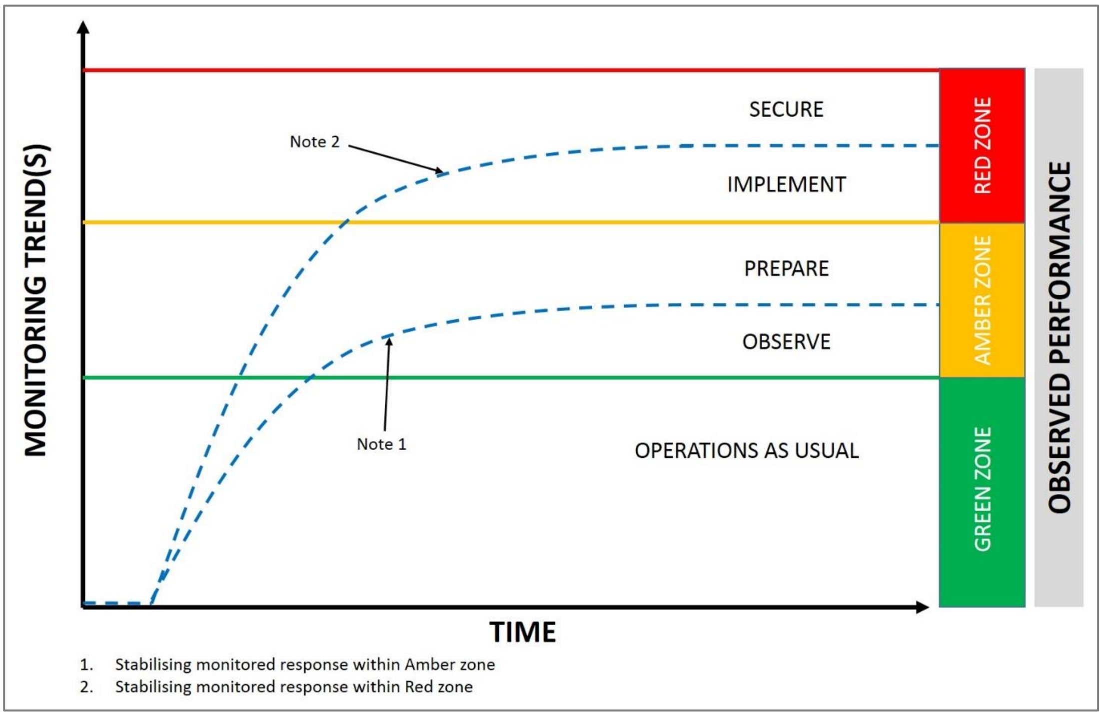

Figure 5-9: Observed performance zones for a three-level system of instrumentation and monitoring

Other systems could also be explored as part of instrumentation and monitoring plan development.

Movement limits for each of these observed performance zones will vary for each instrument type. The design requirements and intent including the construction works being undertaken will need to be considered. Owner/stakeholder requirements and specifications may also contribute to determining these limits.

The required actions for each observed performance response zone should also be determined. Table 5-15 provides an indicative action procedure for a three-level observed performance zone system. Note that the actions can be tailored to suit the intent and purpose of instrumentation and monitoring.

Table 5-15 Example action procedure for three-level observed performance zone system

Observed Performance Zone	Actions
Green	Monitoring data to be reviewed and interpreted Monitoring and construction to continue as planned Document readings and results
Amber	Monitoring data to be reviewed and interpreted Observe monitoring performance Increase monitoring frequency and extent (as appropriate) Prepare and document contingency / mitigation / control measures Document readings, interpretation, results and response taken

Observed Performance Zone	Actions
Red	Monitoring data to be reviewed and interpreted Increase monitoring frequency and extent (as appropriate) Implement previously developed and documented contingency / mitigation / control measures Confirm latest round of monitoring results Observe monitoring performance In extreme circumstances stop work and review process Engineering intervention to consider further actions Notify appropriate authorities (where required) Document readings, interpretation, results and response taken

5.13.4 Groundwater monitoring instrumentation and responsibility

Monitoring of groundwater may be undertaken via:

- Open standpipes also known as piezometers or monitoring bores
- Vibrating Wire Piezometers (VWP's)
- Flow metres and or weirs at points of inflow or discharge locations
- Flow metres and or weirs at appropriate sites along river reaches of canals where interactions between surface and groundwater are affected by changes in water levels and flow.

Monitoring of groundwater should be continuous via the use of electronic data loggers attached to appropriate pressure recording devices such as pressure transducers or VWP's and flow metres.

Consideration should be given to:

- data collection frequency, this should reflect the location, potential impacts and associated risk and should be continuous
- access to the data, consideration should be given to the chosen location and access to that location, i.e., does it require remote access via telemetry systems
- data quality, the data should be reliable and fit for purpose.

The construction contractor will be responsible for providing a responsibility matrix covering:

- Supply and installation of monitoring equipment
- Monitoring, including frequency and reporting
- Maintenance and or calibration requirements
- Decommissioning requirements.

The proposal does not cross any known groundwater dependent ecosystems, sensitive receivers or registered bores for beneficial use therefore proposal specific monitoring locations which monitor impacts surrounding the station construction sites should be prioritised. Monitoring points should also consider drawdown impacts adjacent to the harbour where potential acid sulfate soils may be impacted and over running tunnels. Monitoring locations should also be chosen to address knowledge gaps in current water table geometry especially in the Hunter Street and CBD area. The above monitoring approach also enables the impacts of groundwater on surface hydrology to be assessed.

5.14 Compliance

5.14.1 Licensing

All groundwater and surface water in the vicinity of this proposal is managed through the Greater Metropolitan Region Water Sharing Plan, which provides rules to manage and allocate the groundwater resources. The Water Sharing Plan including specific rules on taking groundwater near high priority groundwater dependent ecosystems, groundwater dependent culturally significant sites, sensitive environmental areas (first/second order streams), and near other licenced bores. The groundwater source relevant to this proposal is the Sydney Central Basin Groundwater Source.

The NSW Aquifer Interference Policy states the licensing requirements for any activities that interfere with, or take water from, an aquifer. This proposal sites constitute aquifer interference activities as the excavations would allow groundwater ingress which includes the collection and disposal of groundwater. These groundwater inflows remove water from the aquifer and must be accounted for within the extraction limits of the Water Sharing Plan.

In general, a water access licence is required for the removal of water from an aquifer. Transport authorities are exempt from the requirement to hold a licence for the take of water under Clause 21 and Schedule 4, Part 3 of the Water Management (General) Regulation 2018. Sydney Metro must still satisfy the requirements of licensing set out in the Greater Metropolitan Region Water Sharing Plan and satisfy the approval requirements of the NSW Aquifer Interference Policy.

The NSW Aquifer Interference Policy specifies that the application for the take of water must be supported by robust predictions of the volumetric take from the aquifer(s) to ensure compliance with licenced volumes, and with the established limits for the aquifer as stated in the Water Sharing Plan. Inflow volumes and the methods used to predict them have been outlined in section 5.

The total inflow across this proposal (Table 5-16) is predicted to be up to 77.2 megalitres in the first year, and up to 40 megalitres in the second year (total of 120 megalitres over both years).

Table 5-16: Summary of cumulative groundwater take for two year construction period

Element	Inflow Year 1 (ML/year)	Inflow Year 2 (ML/year)
Cross Over Cavern	16.35	0.5
Running Tunnels	2.5	6
Pyrmont Station	23	15
Hunter Street Station	35.3	18.2
Sub total	77.15	39.7

The inflows generated by this proposal would need to be assigned through an annual allocation of unassigned water under the Water Sharing Plan, or by purchasing an existing entitlement if there is insufficient unassigned water.

There is currently about 43,353 megalitres per year that is unassigned under the long-term average annual extraction limit (Greater Metropolitan Region Groundwater Sources, Water Sharing Plan 2011). Annual inflows for this proposal would be less than one per cent of the unassigned water. This proposal is therefore not likely to impact the unassigned water available under the Water Sharing Plan.

Section 5.23 of the EP&A Act, states that a water use approval under section 89, a water management work approval under section 90 or an activity approval (other than an aquifer interference approval) under section 91 of the *Water Management Act 2000*, is not required for approved State Significant Infrastructure. As such, water supply works approvals and water use approvals would not be required for this proposal. However, an aquifer interference approval is required.

5.14.2 Consistency with minimum harm criteria

The *Water Management Act 2000* includes the concept of ensuring 'no more than minimal harm' for both the granting of water access licences and the granting of approvals. While the proposal does not require a licence or approval under the *Water Management Act 2000*, the minimal harm criteria in the *NSW Aquifer Interference Policy* (NSW Office of Water, 2012) have been used for the purposes of assessment as shown in Table 5-17.

This proposal excavations would be predominantly located within the Hawkesbury Sandstone, which is classified as a 'less productive aquifer' because yields are generally less than five litres per second. Of the over 600 WaterNSW registered bores in the greater region, the average reported yield is about 2.7 litres per second, and is a porous rock aquifer.

The minimal impact considerations for this aquifer type are summarised in, together with the response developed in this impact assessment.

Table 5-17: Minimal impact consideration for a loss productive porous rock aquifer

Minimal impact consideration	Response
Water table	
1 Less than or equal to ten percent cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 metres from any: • High priority groundwater dependent ecosystem; or • High priority culturally significant site; listed in the schedule of the relevant water sharing plan A maximum of a two-metre decline cumulatively at any water supply work.	There are no identified high priority groundwater dependent ecosystems or culturally significant sites within the area of predicted groundwater drawdown. There are no identified water supply works within the area of predicted drawdown.
2 If more than ten percent cumulative variation in the water table, allowing for typical climatic “post-water sharing plan” variations, 40 metres from any: • High priority groundwater dependent ecosystem; or • High priority culturally significant site; listed in the schedule of the relevant water sharing plan if appropriate studies demonstrate to the Minister’s satisfaction that the variation would not prevent the long-term viability of the dependent ecosystem or significant site. If more than a two-metre decline cumulatively at any water supply work, then make good provisions should apply.	
Water pressure	
1 A cumulative pressure head decline of not more than a two metre decline, at any water supply work.	There are no identified water supply works within the area of predicted drawdown, that would be affected by groundwater drawdown.
2 If the predicted pressure head decline is greater than consideration (1) above, then appropriate studies are required to demonstrate to the Minister’s satisfaction that the decline would not prevent the long-term viability of the affected water supply works unless make good provisions apply.	
Water quality	

Minimal impact consideration	Response
1 Any change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 metres from the activity.	Where contaminated groundwater, saline groundwater, or acid sulfate soils are present within the groundwater level drawdown zone of influence. This proposal has the potential to alter the groundwater quality between the excavations and the contaminant/saline water sources. These processes mean that this requirement of the NSW Aquifer Interference Policy may not be satisfied. See Section 6 for mitigation measures.
2 If consideration (1) is not met then appropriate studies would need to demonstrate to the Minister's satisfaction that the change in groundwater quality would not prevent the long-term viability of the dependent ecosystem, significant site or affected water supply works.	There are no identified water supply works within the area of potential groundwater impact.
Additional considerations	
Any advice provided to a gateway panel, the Planning and Assessment Commission or the Minister for Planning on a State significant development or State significant infrastructure would also consider the potential for: • Acidity issues to arise, for example exposure of acid sulfate soils • Water logging or water table rise to occur, which could potentially affect land use, groundwater dependent ecosystems and other aquifer interference activities. Specific limits would be determined on a case-by-case basis, depending on the sensitivity of the surrounding land and groundwater dependent ecosystems to waterlogging and other aquifer interference activities to water intrusion.	Where the presence of acid sulfate soils and potential groundwater level drawdown within those soils is confirmed, an acid sulfate soils management plan would be developed for the proposal to reduce the risks associated with oxidation/activation of acid sulfate soils (refer to Chapter 15 (Soils and surface water quality) Water logging is not predicted as drawdown of the groundwater table will occur.

5.14.3 Consistency with Water Sharing Plan rules

All groundwater and surface water relevant to the proposal is managed through the Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources 2011. The Water Sharing Plan provides rules to manage and allocate the groundwater resource, including specific rules on taking groundwater near high priority groundwater dependant ecosystems, groundwater dependent culturally significant sites, sensitive environmental areas, and near licenced bores. The groundwater source relevant to this proposal is the Sydney Central Basin Groundwater Source. While the proposal does not require a licence and/or approval under the *Water Management Act 2000*, these rules have been used for the purposes of assessment as showed in Table 5-18.

Table 5-18: This proposal compliance with Water Sharing Plan Rules

Rule	Required assessment
Part 7 – Rules for granting access licences	Sydney Metro is a transport authority and is therefore exempt of requiring a groundwater access licence for this proposal.
Part 8 – Rules for managing access licences	As per response to Part 7 response.
Part 9 – Rules for water supply work approvals	The approval process would determine distance restrictions to minimise interference between water supply works. In the case of this proposal, the water supply works include temporarily untanked excavations and station caverns, and permanently untanked shafts.
Part 9 – 39 Distance restrictions to minimise interference between water supply works Distance restriction from an approved water supply work nominated by another access licence is 400 metres Distance restriction from an approved water supply work for basic land holder rights only is 100 metres Distance restriction from the property boundary is 50 metres Distance restriction from an approved water supply work nominated by a local water utility or major utility access licence is 1,000 metres Distance restriction from a Department observation bore is 200 metres	All of the distance restrictions identified in Part 9 – 39 are satisfied with the following exception – Construction sites for this proposal sites lie within 50 metres of property boundaries
Part 9 – 40 Rules for water supply works located near contamination sources	Restrictions on water supply works approvals would apply to this proposal where construction dewatering and permanent drainage infrastructure are located in the vicinity of ground contamination.
Part 9 – 41 Rules for water supply works located near sensitive environmental areas	Construction sites for the proposal with potential to induce groundwater level drawdown are not located within 100 metres of a high priority groundwater dependent ecosystem listed in Schedule 4 of the relevant Water Sharing Plan, or within 40 metres of the top of the high bank of a lagoon or any third order or higher order stream, or within 100 metres of the top of an escarpment. The proposal would be located at distances greater than 40 metres from first or second order streams.
Part 9 – 42 Rules for water supply works located near groundwater dependent culturally significant sites	Groundwater-dependent culturally sensitive sites have not been identified within 100 metres of the proposal.

Rule	Required assessment
Part 9 – 44 Rules for water supply works located within distance restrictions	Proposal construction sites that do not comply with the above distance restrictions could have limitations on groundwater take under the Water Sharing Plan. However, with implementation of the mitigation measures, it is expected that such limitations would not be imposed.
Part 10 – Access licence dealing rules	As per response to Part 7

6 Management and mitigation measures

6.1 Approach to management and mitigation

Groundwater issues would be managed in accordance with Sydney Metro's Construction Environmental Management Framework. The Construction Environmental Management Framework requires the preparation of a Groundwater Management Plan and includes the following groundwater management objectives:

- Reduce the potential for drawdown of surrounding groundwater resources
- Prevent the pollution of groundwater through appropriate controls
- Reduce the potential impacts on groundwater dependent ecosystems.

Interactions between mitigation measures in other technical papers and chapters that are relevant to the management of potential groundwater movement impacts include:

- Technical Paper 7 (Hydrology, flooding and water quality) with respect to management of potential water quality
- Technical Paper 8 (Contamination) with respect to management of potential contamination
- Technical Paper 10 (Biodiversity) with respect to management of potential impacts on groundwater dependent ecosystems.

Together, these measures would minimise the potential impacts of This proposal. There are no mitigation measures identified in the assessment of other environmental aspects that are likely to affect the assessment of groundwater movement impacts.

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8 Appendix

Appendix A: Site investigation – groundwater levels

Hole ID	Top Depth	Bottom Depth	Ground level (m)	Water Level (mAHD)	Easting	Northing
RZ_BH01S	7	10	6.39	1.9	330611.47	6250381.61
RZ_BH44s	12	15	2.25	0.94	330884.43	6250613.29
RZ_BH47s	15	18	2.5	1.06	331027.87	6250703.96
TC_BH01S	3	6	2.55	0.85	330660.57	6250304.92
TC_BH07S	3	6	2.06	1.3	330746.03	6250373.57
TC_BH09S	2	5	2.29	0.6	330830.31	6250444.46
HB_BH08S	10	13	1.43	0.8	328750.60	6250135.51
BH002	14	17	5.3	2.8	331227.00	6246461.00
BH023	11.5	14.5	105.5		331693.00	6258112.00
BH026	22	28.2	104	94.8	331603.00	6258046.00
BH008	17	21.5	24.1	2.7	334259.00	6250394.00
BH009	19.1	21	25.4	13	334356.00	6250387.00
BH012	25.2	31.2	24.3	8.9	334486.00	6251171.00
BH403	16.5	22.5	15.1	10.5	333619.00	6247626.00
BH404	16.5	29.5	15.4	9.2	333621.00	6247735.00
EP_BH06	10	13	7.601	3.95	331025.39	6250903.92
EP_BH07	10	13	10.478	3	331082.28	6250898.80
HB_BH12	27	30	2.13	1.83	329047.41	6250099.10
HB_BH14	37	40	4.2	1.95	329206.55	6250086.27
HB_BH15	19	22	17.8	8.11	329396.41	6250142.83
IC_BH02	5	11	20.77	17.4	330334.97	6251646.37

Hole ID	Top Depth	Bottom Depth	Ground level (m)	Water Level (mAHD)	Easting	Northing
MT_BH02	42	45	34.1	8	329696.10	6249704.00
MT_BH07	43	46	24.41	5.7	330355.81	6249914.91
MT_BH14	27	30	27.314	23.73	331168.37	6248149.99
MT_BH19	55	58	16.07	11.8	331680.25	6246735.87
MT_BH21	47	50	25.05	13.2	330066.72	6249771.00
RZ_BH01D	22	25	6.3	1.55	330608.87	6250381.26
RZ_BH15	18	21	6.02	1.6	330611.47	6250381.61
RZ_BH16	17	20	5.82	1.53	330609.43	6250409.41
RZ_BH19	19	22	2.46	1.48	330822.45	6250626.95
RZ_BH26	20	23	2.84	1.65	331066.28	6250835.05
RZ_BH28	27	30	2.83	1.75	331126.56	6250818.78
RZ_BH30	16	19	2.04	1.6	331192.90	6250834.96
RZ_BH38	28	31	2.27	1.59	330726.61	625012.07
RZ_BH44d	25	28	2.29	1.23	330885.77	6250613.96
RZ_BH47d	27	30	2.3	1.6	331025.23	6250701.67
RZ_BH49	13	16	5.99	1.29	330730.38	6250461.58
RZ_BH50	22	25	1.92	1.37	331255.63	6250841.07
RZ_BH51	19	22	2.15	1.72	331206.58	6250813.32
RZ_BH52	32	35	2.53	1.52	331163.77	6250784.58
RZ_BH60	56	59	24.96	12.5	330317.83	6250589.57
RZ_BH67	46	49	12.84	8.63	330961.48	6250999.73
SP_BH01	36	39	17.71	5	331750.58	6246432.73
SP_BH02	4	10	19.42	16.35	331844.84	6246375.94
SP_BH04	32	35	12.23	0.25	331657.95	6246185.60

Hole ID	Top Depth	Bottom Depth	Ground level (m)	Water Level (mAHD)	Easting	Northing
TC_BH01D	25	28	2.54	1.5	330661.99	6250305.25
TC_BH06	4.5	7.5	2.65	1.25	330610.16	6250298.14
TC_BH07D	19	22	2.03	1.7	330610.16	6250298.14
TC_BH08	5	8	2.24	0.58	330747.41	6250374.95
TC_BH09D	21	24	2.25	1.56	330818.34	6250435.89
BH006	26.5	29.5	20.6	5.85	334064.00	6249133.00
BH017	35	38.8	62.9	43.5	334111.00	6254365.00
HB_BH03	14	17	6.15	3.75	327764.93	6250217.19
HB_BH08D	22	25	1.49		328751.96	6250138.18
BH018	19.3	25.3	90.75	77.8	333390.00	6255706.00
BH020	15.1	21.1	78.5	74.6	332695.00	6256655.00
BH002A	1.1	5.6	5.3	3.5	331226.00	6246467.00
BH019	4	7	84.4	81.9	333308.00	6255819.00
SMW_BH062	-28		34.12	18	330275.40	6251048.00
SMW_BH052	14.2	17.2	11.78	-2.5	333150.90	6250771.30
SMW_BH058	-30.38		6.62	0.1	329160.00	6250750.00
SMW_BH066s	2	6	4.14	0.4	331517.00	6251104.50
SMW_BH067s	2.5	6	2.92	0.8	331614.90	6251063.80
SMW_BH100	-14.95		8.7	-5.56	334270.10	6251300.70
SMW_BH101	-5.2		8.7	2.97	334271.40	6251301.20

Appendix B: Groundwater Bore Search

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW042159	24	0	335193	6246227	24.82	Monitoring
GW108418	6	6	334917	6246185	26.52	Water Supply
GW115723	9	0	334847.9	6246180	0	Water Supply
GW075017	28.5	29.5	335196.7	6246243	8.565	Monitoring

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW108403	5	5	334940	6246208	26.28	Water Supply
GW111557	8	8	334929	6246207	26.28	Water Supply
GW107881	7	0	334955	6246223	26.2	Water Supply
GW104928	9	9	335331	6246292	31.15	Water Supply
GW107643	7	7	335159	6246268	28.47	Water Supply
GW107348	13.42	13.42	335279	6246295	31.62	Water Supply
GW107430	9.15	9.15	335350	6246312	31.03	Water Supply
GW111158	14	14	334872	6246233	25.78	Water Supply
GW105964	9.5	9.5	335237	6246295	31.35	Water Supply
GW105999	10.675	10.68	335309	6246314	31.33	Water Supply
GW108734	6.1	6.1	335017	6246266	26.94	Water Supply
GW107137	7.625	7.63	335361	6246326	29.91	Water Supply
GW106945	9.5	9.5	335204	6246301	30.56	Water Supply
GW105492	6.71	6.71	335136	6246310	27.37	Water Supply
GW017345	13.7	13.7	334289	6246182	24.11	Commercial and Industrial
GW025717	3.6	0	334856	6246279	25.24	Water Supply
GW051729	8.5	8.5	334264	6246181	23.87	Monitoring
GW108440	5	5	334989	6246309	26.37	Water Supply
GW107534	6.1	6.1	335377	6246382	28.15	Water Supply
GW105508	7	0	335063	6246336	27.03	Water Supply
GW051727	8	8	334084	6246178	22.24	Monitoring
GW110538	8	8	335180	6246367	29.05	Water Supply
GW112385	5.49	5.49	334904	6246327	0	Water Supply
GW106182	4	4	334870	6246326	25.5	Water Supply
GW108703	8	0	335171	6246379	28.59	Water Supply
GW107213	6	6	335030	6246359	26.89	Water Supply
GW105440	5.19	5.19	335030	6246361	26.89	Water Supply
GW109118	7.625	0	335156	6246384	27.83	Water Supply
GW107603	7	7	334995	6246357	26.8	Water Supply
GW051726	8	8	334083	6246209	22.24	Monitoring
GW105134	5	5	334948	6246358	26.46	Water Supply
GW072922	6.7	6.7	335353	6246428	28.4	Water Supply
GW072622	16	16	334406	6246273	23.78	Other
GW072787	5.5	5.5	334941	6246364	26.46	Water Supply
GW111621	6	6	335023	6246400	26.66	Water Supply
GW113310	9	9	335084	6246411	0	Water Supply
GW051725	8	8	334057	6246240	22.11	Monitoring
GW107391	7.015	7.02	335328	6246457	28.54	Water Supply
GW051728	8.3	8.3	334185	6246273	22.76	Monitoring
GW107551	6.71	6.71	335050	6246418	26.43	Water Supply
GW105575	7	7	335077	6246425	26.61	Water Supply
GW114917	9.15	9.15	334923	6246416	0	Water Supply
GW111488	3	3	334611	6246363	23.53	Monitoring
GW111487	2.4	2.4	334579	6246369	23.14	Monitoring
GW105736	0	0	335007	6246445	25.97	Unknown
GW105040	8	8	335231	6246483	26.83	Water Supply
GW111486	2	2	334603	6246385	23.14	Monitoring
GW103774	6	0	335153	6246480	26.33	Water Supply

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW203385	6.2	6.2	334266	6246334	0	Monitoring
GW101933	2.2	0	335141	6246484	26.33	Water Supply
GW203387	7	7	334345	6246354	0	Monitoring
GW203386	2.8	2.8	334345	6246354	0	Monitoring
GW025718	3.6	3.7	335079	6246480	26.16	Water Supply
GW106772	5	5	335120	6246489	26.16	Water Supply
GW110270	6	6	335088	6246485	26.16	Water Supply
GW106093	5.185	5.19	335065	6246500	26.54	Water Supply
GW108491	7	7	334967	6246488	25.96	Water Supply
GW108400	7.015	0	335212	6246532	26.16	Unknown
GW108632	7.32	7.32	334985	6246504	26.49	Water Supply
GW106028	5	5	335302	6246558	28.88	Water Supply
GW104834	5.8	5.8	335011	6246512	26.61	Water Supply
GW106364	0	0	335083	6246529	26.54	Unknown
GW109546	8.14	0	334355	6246419	22.85	Monitoring
GW100359	5.5	5.5	335052	6246538	27.16	Water Supply
GW023585	4.5	4.6	334977	6246533	27.24	Water Supply
GW112397	7.32	7.32	335203	6246571	0	Water Supply
GW023144	4.8	0	335066	6246551	27	Water Supply
GW108846	8	8	334972	6246537	27.24	Water Supply
GW109547	13.6	0	334362	6246437	22.84	Monitoring
GW106058	7.5	7.5	334878	6246537	25.66	Water Supply
GW100939	5.5	5.5	335034	6246564	27.96	Water Supply
GW110539	10	10	335202	6246602	27.17	Water Supply
GW106856	7.93	7.93	335059	6246586	27.78	Water Supply
GW113770	5	5	334792	6246559	0	Monitoring
GW111592	20	20	334957	6246589	28.11	Water Supply
GW106602	6.1	6.1	335191	6246630	28.34	Water Supply
GW113771	5	5	334765	6246565	0	Monitoring
GW109543	11.3	0	334237	6246484	22.75	Monitoring
GW113768	5	5	334799	6246580	0	Monitoring
GW113769	5.5	5.5	334775	6246578	0	Monitoring
GW109544	14	0	334417	6246524	22.11	Monitoring
GW105940	0	0	335010	6246631	29.72	Unknown
GW113776	4.3	4.3	334720	6246584	0	Monitoring
GW113766	5.5	5.5	334801	6246609	0	Monitoring
GW024118	3	3	334873	6246624	25.94	Water Supply
GW113774	5.5	5.5	334765	6246608	0	Monitoring
GW113767	5.5	5.5	334774	6246614	0	Monitoring
GW113764	5	5	334803	6246623	0	Monitoring
GW113765	5	5	334779	6246620	0	Monitoring
GW113772	4.3	4.3	334769	6246621	0	Monitoring
GW113773	5	5	334742	6246617	0	Monitoring
GW113775	5	5	334726	6246623	0	Monitoring
GW113762	4.3	4.3	334806	6246638	0	Monitoring
GW113763	4.3	4.3	334800	6246637	0	Monitoring
GW109545	13.9	0	334306	6246557	22.26	Monitoring
GW113761	4.5	4.5	334789	6246640	0	Monitoring

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW113760	5	5	334792	6246642	0	Monitoring
GW109504	7.48	0	334296	6246560	22.26	Monitoring
GW113759	4.3	4.3	334755	6246653	0	Monitoring
GW113758	4.5	4.5	334747	6246655	0	Monitoring
GW109066	7.5	0	334880	6246682	26.9	Water Supply
GW113757	5	5	334741	6246659	0	Monitoring
GW112480	7	7	333781	6246528	0	Monitoring
GW112479	7	7	333743	6246534	0	Monitoring
GW112478	4.5	4.5	333824	6246549	0	Monitoring
GW104125	15.7	22	334729	6246701	25.12	Other
GW111136	11	11	334997	6246770	30.41	Water Supply
GW108882	6	0	334892	6246756	26.58	Water Supply
GW106046	0	0	333636	6246554	15.88	Unknown
GW106083	18.9	20.1	335207	6246827	30.98	Water Supply
GW013629	21.9	21.9	335180	6246825	30.99	Water Supply
GW114562	4	2.7	332807	6246449	0	Monitoring
GW108653	12	12	335260	6246864	32.53	Water Supply
GW114561	4	4	332799	6246455	0	Monitoring
GW105747	8.235	8.24	335018	6246828	31.53	Water Supply
GW114563	4	3.9	332818	6246463	0	Monitoring
GW109791	4.1	4.1	333721	6246619	15.49	Monitoring
GW109790	4	4	333740	6246626	15.68	Monitoring
GW109792	4.2	4.2	333687	6246622	15.27	Monitoring
GW109789	5	5	333709	6246662	15.07	Monitoring
GW106110	20.5	23.2	335290	6246945	35.62	Water Supply
GW106030	20	20.5	335207	6246950	36.19	Water Supply
GW107135	7	7	334927	6246929	29.69	Water Supply
GW107134	7	7	334906	6246959	29.98	Water Supply
GW106004	19.5	23.2	335042	6246991	35.5	Water Supply
GW107133	7	7	334925	6246974	29.98	Water Supply
GW113814	3.8	3.8	333016	6246665	0	Monitoring
GW017342	15.5	15.5	333739	6246789	15.25	Commercial and Industrial
GW113817	3.7	3.7	332988	6246671	0	Monitoring
GW017684	14.9	14.9	333662	6246787	14.05	Commercial and Industrial
GW113816	5.75	5.75	332861	6246662	0	Monitoring
GW113820	5	5	332988	6246690	0	Monitoring
GW113821	4.6	4.6	333031	6246703	0	Monitoring
GW113806	4.1	4.1	332986	6246705	0	Monitoring
GW113819	3.25	3.25	332948	6246700	0	Monitoring
GW113805	4.6	4.6	332998	6246723	0	Monitoring
GW113809	4.5	4.5	333088	6246755	0	Monitoring
GW113810	4.6	4.6	332969	6246740	0	Monitoring
GW114924	9	9	331299	6246465	0	Monitoring
GW114925	6.1	6.1	331322	6246473	0	Monitoring
GW113808	4.2	4.2	333087	6246770	0	Monitoring
GW113818	4.4	4.4	332975	6246752	0	Monitoring
GW114168	8.7	8.7	334022	6246943	0	Monitoring
GW113799	4.1	4.1	333085	6246786	0	Monitoring

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW113807	4.2	4.2	333116	6246792	0	Monitoring
GW113822	1.86	1.86	332995	6246774	0	Monitoring
GW113801	4.5	4.5	333046	6246787	0	Monitoring
GW113800	4.6	4.6	333065	6246798	0	Monitoring
GW114169	9.8	9.8	334006	6246958	0	Monitoring
GW113812	6.1	6.1	332969	6246796	0	Monitoring
GW114167	5.5	5.5	334028	6246974	0	Monitoring
GW113813	6.1	6.1	332982	6246807	0	Monitoring
GW113811	5.4	5.4	332968	6246812	0	Monitoring
GW113823	3.2	3.2	333029	6246835	0	Monitoring
GW114985	6	6	332539	6246759	0	Monitoring
GW065460	12	0	334428	6247078	24.95	Commercial and Industrial
GW114984	6	6	332546	6246770	0	Monitoring
GW102360	6	0	333147	6246871	10.76	Monitoring
GW113824	3.05	3.05	333035	6246857	0	Monitoring
GW114986	6	6	332534	6246784	0	Monitoring
GW102359	6	0	333146	6246901	11.02	Monitoring
GW102361	6	0	333146	6246901	11.02	Monitoring
GW113815	6.1	6.1	332950	6246887	0	Monitoring
GW102365	6	0	333146	6246932	11.31	Monitoring
GW113804	6	6	332988	6246909	0	Monitoring
GW111164	8	8	332686	6246860	11.62	Water Supply
GW113803	5.8	0	333001	6246929	0	Monitoring
GW102362	3	0	333171	6246963	11.78	Monitoring
GW102363	3	0	333145	6246963	11.54	Monitoring
GW102364	3	0	333145	6246963	11.54	Monitoring
GW102356	6	0	333120	6246963	11.92	Monitoring
GW113802	6.1	6.1	332978	6246947	0	Monitoring
GW102358	6	0	333145	6246994	11.55	Monitoring
GW102357	6	0	333093	6246993	12.91	Monitoring
GW113035	5	5	333571	6247205	0	Monitoring
GW113036	4	4	333566	6247220	0	Monitoring
GW113475	6	6	334335	6247359	0	Monitoring
GW113038	5	5	333577	6247239	0	Monitoring
GW113037	5	5	333582	6247245	0	Monitoring
GW111960	6	6.6	334321	6247372	0	Monitoring
GW113039	5	5	333561	6247245	0	Monitoring
GW112129	5.5	5.5	334225	6247360	0	Monitoring
GW113474	6	6	334356	6247384	0	Monitoring
GW113473	3	3	334433	6247399	0	Monitoring
GW111959	6	6	334261	6247374	0	Monitoring
GW112128	5.5	5.5	334235	6247381	0	Monitoring
GW113777	6	6	334459	6247426	0	Monitoring
GW113778	5	5	334432	6247422	0	Monitoring
GW113797	4.13	4.13	334402	6247422	0	Monitoring
GW113779	9	9	334433	6247430	0	Monitoring
GW113780	8	8	334402	6247427	0	Monitoring
GW113254	3.6	3.6	334392	6247426	0	Monitoring

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW112127	4.5	4.5	334239	6247401	0	Monitoring
GW112711	3.6	3.6	334398	6247432	0	Monitoring
GW048937	24.4	24.4	335036	6247551	40.26	Other
GW113255	4	4	334403	6247446	0	Monitoring
GW113784	7	7	334444	6247462	0	Monitoring
GW113469	3.1	3.1	334372	6247451	0	Monitoring
GW112712	4	4	334407	6247457	0	Monitoring
GW113256	4.05	4.05	334400	6247469	0	Monitoring
GW113781	4.5	4.5	334518	6247490	0	Monitoring
GW113257	4.1	4.1	334417	6247488	0	Monitoring
GW111692	1.3	1.3	329704	6246701	0	Monitoring
GW112713	4.05	4.05	334405	6247491	0	Monitoring
GW113258	4.1	4.1	334408	6247498	0	Monitoring
GW111958	6	6	333507	6247347	0	Monitoring
GW104266	22.8	35.6	335017	6247601	38.83	Monitoring
GW113468	3.5	3.5	334379	6247495	0	Monitoring
GW113788	11	11	334463	6247512	0	Monitoring
GW113782	8	8	334463	6247512	0	Monitoring
GW113785	4	4	334463	6247512	0	Monitoring
GW112714	4.1	4.1	334409	6247508	0	Monitoring
GW114401	2.2	2.2	334498	6247523	0	Monitoring
GW114402	2.2	2.2	334474	6247527	0	Monitoring
GW110351	60	0	332651	6247224	12.47	Other
GW113789	10.95	10.95	334505	6247539	0	Monitoring
GW114403	2.2	2.2	334446	6247531	0	Monitoring
GW114919	3	3	332163	6247149	0	Monitoring
GW113798	4.8	4.8	334501	6247542	0	Monitoring
GW113787	4.8	4.8	334501	6247542	0	Monitoring
GW112715	4.1	4.1	334423	6247530	0	Monitoring
GW113794	11.15	11.15	334435	6247535	0	Monitoring
GW109750	3.5	3.5	334461	6247540	28.19	Monitoring
GW108245	20.8	20.8	334890	6247612	31.74	Other
GW113786	3	3	334499	6247547	0	Monitoring
GW111080	5	5	334555	6247560	32.24	Monitoring
GW111081	4	4	334545	6247561	32.24	Monitoring
GW109745	3.5	3.5	334439	6247544	27.6	Monitoring
GW111406	4.8	4.8	334513	6247557	30.54	Monitoring
GW113467	3.4	3.4	334388	6247537	0	Monitoring
GW114395	3.2	3.2	334481	6247553	0	Monitoring
GW114392	2.4	2.4	334496	6247556	0	Monitoring
GW111082	4	4	334532	6247563	32.24	Monitoring
GW113791	4	4	334429	6247547	0	Monitoring
GW017870	17.9	18	334958	6247642	35.8	Commercial and Industrial
GW114389	3.2	3.2	334502	6247566	0	Monitoring
GW109749	4.5	4.5	334468	6247562	28.19	Monitoring
GW109752	3.4	3.4	334499	6247569	29.11	Monitoring
GW114397	3.2	3.2	334455	6247562	0	Monitoring
GW113783	4.6	4.6	334505	6247571	0	Monitoring

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW114394	4.2	4.2	334470	6247565	0	Monitoring
GW111407	4.8	4.8	334508	6247572	30.27	Monitoring
GW113795	3.9	3.9	334419	6247559	0	Monitoring
GW113796	11.05	11.05	334419	6247562	0	Monitoring
GW111405	4.8	4.8	334518	6247580	30.27	Monitoring
GW114400	3.2	3.2	334430	6247567	0	Monitoring
GW114387	3.2	3.2	334504	6247580	0	Monitoring
GW109746	4.2	4.2	334445	6247573	28.25	Monitoring
GW114388	5.2	5.2	334490	6247583	0	Monitoring
GW109747	3.8	3.8	334469	6247580	28.41	Monitoring
GW113472	6.2	6.2	334616	6247605	0	Monitoring
GW113790	5.85	5.85	334471	6247581	0	Monitoring
GW113793	4.1	4.1	334426	6247577	0	Monitoring
GW109744	4	4	334420	6247577	28.58	Monitoring
GW114399	4.2	4.2	334420	6247578	0	Monitoring
GW109748	3.8	3.8	334497	6247592	29.11	Monitoring
GW114391	4.2	4.2	334471	6247591	0	Monitoring
GW114386	5.2	5.2	334493	6247597	0	Monitoring
GW114396	5.2	5.2	334441	6247592	0	Monitoring
GW109751	3.5	3.5	334438	6247592	28.25	Monitoring
GW113471	4.5	4.5	334629	6247626	0	Monitoring
GW113792	3.7	3.7	334455	6247599	0	Monitoring
GW114390	3.2	3.2	334462	6247602	0	Monitoring
GW114393	4.2	4.2	334447	6247604	0	Monitoring
GW114398	4.2	4.2	334423	6247607	0	Monitoring
GW017340	18.5	18.6	334982	6247704	37.54	Commercial and Industrial
GW037956	0	21.1	334804	6247675	35.13	Commercial and Industrial
GW100546	14.5	14.5	335294	6247765	39.02	Monitoring
GW111015	7	7	334606	6247653	33.22	Monitoring
GW113470	5.7	5.7	334657	6247662	0	Monitoring
GW042158	21.15	0	335282.6	6247779	43.708	Monitoring
GW114895	6	6	333583	6247498	0	Monitoring
GW111014	6.5	6.5	334576	6247666	32.51	Monitoring
GW017869	17.9	18	334930	6247734	38.64	Commercial and Industrial
GW111016	4.4	4.5	334468	6247664	30.96	Monitoring
GW111686	3.5	3.5	329728	6246909	17.16	Monitoring
GW111434	8	8	334673	6247739	34.89	Monitoring
GW111687	4.25	4.25	329742	6246916	17.38	Monitoring
GW111433	6.3	7	334694	6247805	35.52	Monitoring
GW106192	6	6	333418	6247611	19.11	Water Supply
GW105938	0	0	332733	6247637	15.62	Unknown
GW109732	4.3	4.3	332071	6247629	25.47	Monitoring
GW109733	2.4	2.4	332082	6247631	25.47	Monitoring
GW109730	6.5	6.5	332089	6247634	24.78	Monitoring
GW109731	6	6	332066	6247634	25.47	Monitoring
GW109729	6	6	332074	6247641	25.47	Monitoring
GW071907	180	180	334034	6247997	30	Other
GW104133	20.5	0	335155	6248200	37.84	Other

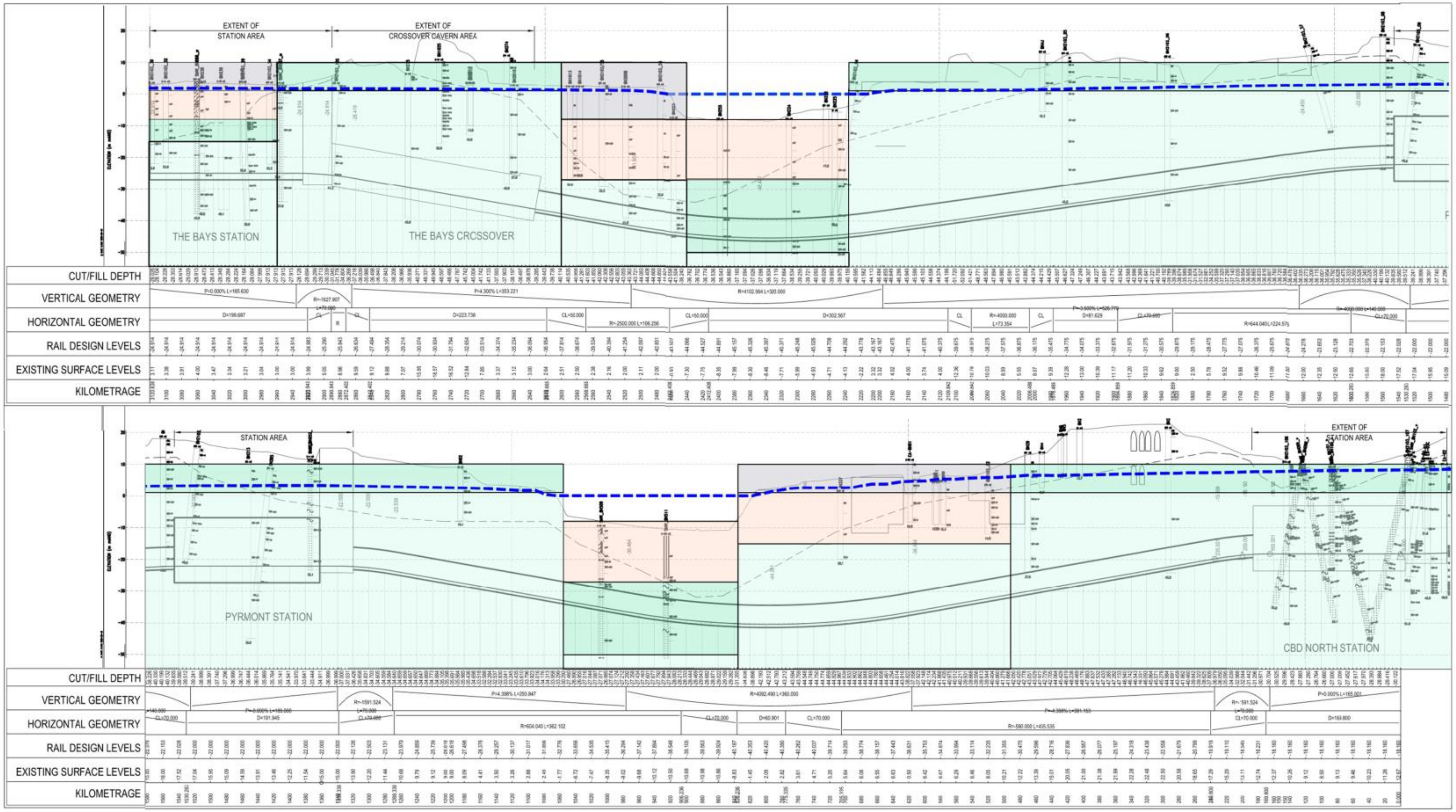
State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW111353	7	7	331440	6247590	34.73	Monitoring
GW111352	8	8	331445	6247600	34.73	Monitoring
GW111351	9	9	331436	6247601	34.73	Monitoring
GW111350	7.5	7.5	331456	6247614	35.01	Monitoring
GW105525	5.49	5.49	335025	6248227	37.56	Water Supply
GW105920	0	0	335321	6248323	40.14	Water Supply
GW104131	20	0	335213	6248371	38.14	Other
GW105317	6.5	6.5	331965	6247846	37.56	Monitoring
GW110247	210	210	332357	6248363	44.22	Water Supply
GW102476	4	0	334832	6248965	50.35	Monitoring
GW112182	30	30	335240	6249077	0	Monitoring
GW103258	7	7	331116	6248466	20.59	Monitoring
GW103260	10.7	10.7	331116	6248466	20.59	Monitoring
GW103261	7.4	7.4	331116	6248466	20.59	Monitoring
GW103259	2.5	2.5	331115	6248466	20.59	Monitoring
GW112181	30	30	335201	6249161	0	Monitoring
GW113885	7	7	333710	6248956	0	Monitoring
GW113883	6.1	6.1	333712	6248959	0	Monitoring
GW113893	8.5	8.5	333711	6248960	0	Monitoring
GW113892	7	7	333708	6248960	0	Monitoring
GW113891	6.8	6.8	333705	6248960	0	Monitoring
GW113890	6	6	333700	6248961	0	Monitoring
GW113882	6.1	6.1	333696	6248961	0	Monitoring
GW113881	6.1	6.1	333691	6248963	0	Monitoring
GW113855	5	5	333710	6248970	0	Monitoring
GW113856	6.2	6.2	333708	6248970	0	Monitoring
GW113886	5.8	5.8	333680	6248970	0	Monitoring
GW113860	6.5	6.5	333712	6248976	0	Monitoring
GW113875	7.5	7.5	333698	6248974	0	Monitoring
GW113884	6.8	6.8	333698	6248974	0	Monitoring
GW109500	4.8	0	333698	6248974	23.96	Monitoring
GW113859	6.1	6.1	333677	6248973	0	Monitoring
GW113874	7	7	333699	6248977	0	Monitoring
GW113873	6	6	333698	6248979	0	Monitoring
GW113889	6.7	6.7	333685	6248979	0	Monitoring
GW113857	6	6	333685	6248983	0	Monitoring
GW113858	6.3	6.3	333682	6248985	0	Monitoring
GW113887	5.7	5.7	333664	6248987	0	Monitoring
GW113888	5.5	5.5	333668	6248990	0	Monitoring
GW113879	5.3	5.3	333711	6249000	0	Monitoring
GW113862	3.8	3.8	333564	6248987	0	Monitoring
GW113863	4.6	4.6	333563	6248991	0	Monitoring
GW113864	4.5	4.5	333563	6248995	0	Monitoring
GW113865	6.5	6.5	333563	6248998	0	Monitoring
GW113866	3	3	333562	6249001	0	Monitoring
GW113867	3.5	3.5	333562	6249004	0	Monitoring
GW113868	3.7	3.7	333562	6249008	0	Monitoring
GW113869	6	6	333562	6249011	0	Monitoring

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW113878	7	7	333596	6249017	0	Monitoring
GW113877	5.5	5.5	333587	6249019	0	Monitoring
GW113870	4.8	4.8	333561	6249016	0	Monitoring
GW113880	5	5	333544	6249014	0	Monitoring
GW113876	7.8	7.8	333578	6249020	0	Monitoring
GW113872	8	8	333572	6249020	0	Monitoring
GW113871	6	6	333561	6249019	0	Monitoring
GW113861	6.5	6.5	333537	6249043	0	Monitoring
GW109503	5.2	0	333460	6249045	22.92	Monitoring
GW112180	30	30	335167	6249351	0	Monitoring
GW109502	6.4	0	333442	6249090	21.19	Monitoring
GW200690	6	0	334928	6249340	59.43	Water Supply
GW109239	7.45	7.45	335107	6249385	60.63	Monitoring
GW109238	7.5	7.5	335069	6249391	61.82	Monitoring
GW109240	7.5	7.5	335100	6249420	61.04	Monitoring
GW109501	6	0	333441	6249156	20.55	Monitoring
GW112179	30	30	335136	6249527	0	Monitoring
GW111087	8.7	8.7	329693	6248632	38.08	Monitoring
GW111088	9	9	329706	6248636	38.08	Monitoring
GW111089	9	9	329715	6248641	38.27	Monitoring
GW109646	8.2	8.2	333312	6249293	15.05	Monitoring
GW109230	1.8	0	331802	6249055	24.04	Monitoring
GW109231	3.2	0	331787	6249063	22.61	Monitoring
GW109648	6.2	6.2	333342	6249333	15.1	Monitoring
GW109649	7.2	7.2	333320	6249352	15.05	Monitoring
GW111408	4.4	4.4	332066	6249142	29.38	Monitoring
GW112178	30	30	335084	6249714	0	Monitoring
GW112177	30	30	335120	6249949	0	Monitoring
GW112176	30	30	335121	6249958	0	Monitoring
GW112175	30	30	335131	6250024	0	Monitoring
GW112184	30	30	335146	6250173	0	Monitoring
GW110496	4	4	330809	6249527	29.29	Monitoring
GW110497	4	4	330787	6249544	28.6	Monitoring
GW110498	4	4	330795	6249554	28.6	Monitoring
GW112183	30	30	335161	6250376	0	Monitoring
GW110371	4	4	332598	6250115	9.79	Monitoring
GW110372	4	4	332606	6250121	9.79	Monitoring
GW110374	4	4	332603	6250122	8.2	Monitoring
GW110370	4	4	332598	6250123	8.2	Monitoring
GW110373	4	4	332590	6250126	8.2	Monitoring
GW114004	6.2	6.2	328896	6249585	0	Monitoring
GW114003	6.15	6.15	328849	6249585	0	Monitoring
GW114005	8	8	328865	6249631	0	Monitoring
GW111331	6	6	332742	6250509	2.98	Monitoring
GW109651	2.5	2.55	330203	6250093	26.98	Monitoring
GW114187	6	6	332760	6250542	0	Monitoring
GW111330	4	4	332729	6250538	3.07	Monitoring
GW114182	11.55	11.55	332763	6250568	0	Monitoring

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW111329	6	6	332704	6250560	3.38	Monitoring
GW114184	6	6	332799	6250576	0	Monitoring
GW114185	3	3	332727	6250577	0	Monitoring
GW114183	9.35	9.35	332766	6250591	0	Monitoring
GW114186	3	3	332785	6250595	0	Monitoring
GW111654	3	3	329345	6250163	14.35	Monitoring
GW111663	4	4	329182	6250138	9.28	Monitoring
GW111653	2.4	2.5	329146	6250135	9.3	Monitoring
GW109087	8.5	8.5	333783	6251252	13.2	Monitoring
GW109086	5.68	5.68	333781	6251262	13.2	Monitoring
GW109085	5.68	5.68	333786	6251263	13.2	Monitoring
GW113601	14.2	14.2	333687	6251505	0	Monitoring
GW113600	14.2	14.2	333687	6251505	0	Monitoring
GW113599	13.5	13.5	333687	6251505	0	Monitoring
GW113603	14.5	14.5	333717	6251525	0	Monitoring
GW113602	17	17	333727	6251531	0	Monitoring
GW113604	8.2	8.2	333735	6251538	0	Monitoring
GW113605	3	3	333744	6251547	0	Monitoring
GW113611	7.5	7.5	333687	6251539	0	Monitoring
GW113606	13	13	333686	6251550	0	Monitoring
GW113607	7.2	7.2	333727	6251558	0	Unknown
GW113608	13	13	333754	6251570	0	Monitoring
GW113609	3.45	3.45	333754	6251570	0	Monitoring
GW113598	13.2	13.2	333745	6251581	0	Monitoring
GW113610	12.2	12.2	333722	6251579	0	Monitoring
GW113612	13	13	333710	6251585	0	Monitoring
GW113596	14.1	14.1	333741	6251591	0	Monitoring
GW113597	9.5	9.5	333738	6251600	0	Monitoring
GW113566	3	3	333667	6251601	0	Monitoring
GW113565	4	4	333619	6251603	0	Monitoring
GW113564	7	7	333582	6251610	0	Monitoring
GW113563	11.7	11.7	333577	6251647	0	Monitoring
GW113562	10.7	10.7	333562	6251731	0	Monitoring
GW113561	4.5	4.5	333555	6251791	0	Monitoring
GW113560	3.6	3.6	333548	6251850	0	Monitoring
GW102671	4.8	4.8	331651	6251559	7.99	Monitoring
GW102672	9	9	331676	6251590	7.65	Monitoring
GW112873	15.1	15.1	334851	6252129	0	Monitoring
GW113559	4	4	333544	6251910	0	Monitoring
GW112871	20	20	334880	6252193	0	Monitoring
GW113558	14	14	333541	6251980	0	Monitoring
GW112872	20.12	20.12	334881	6252249	0	Monitoring
GW113557	12	12	333535	6252060	0	Monitoring
GW109712	5.8	5.8	332788	6251938	-9999	Monitoring
GW109713	6	6	332750	6251951	-9999	Monitoring
GW109716	6	6	332729	6251981	8.6	Monitoring
GW109714	5.9	5.9	332745	6252032	14.29	Monitoring
GW115131	1.4	1.4	332733	6252030	0	Monitoring

State Bore ID	Bore Depth	Drilled Depth	Easting	Northing	Ref Elev	Type Class
GW115130	10	10	332733	6252051	0	Monitoring
GW113555	14	14	333533	6252205	0	Monitoring
GW113556	14	14	333524	6252205	0	Monitoring
GW109715	5.9	5.9	332556	6252060	12.97	Monitoring
GW102655	25	25	330131	6251717	10.97	Monitoring
GW113553	5.2	5.2	333632	6252368	0	Monitoring
GW113554	5	5	333529	6252357	0	Monitoring
GW111570	6	6	333701	6252417	2.06	Monitoring
GW111571	6	6	333707	6252420	1.87	Monitoring
GW109209	4.5	0	331813	6252542	18.32	Water Supply

Appendix C: Groundwater table set up along the running tunnels and stations (pre-construction)



mf: Man-made fill (HK= 1 – 0.1 m/day)

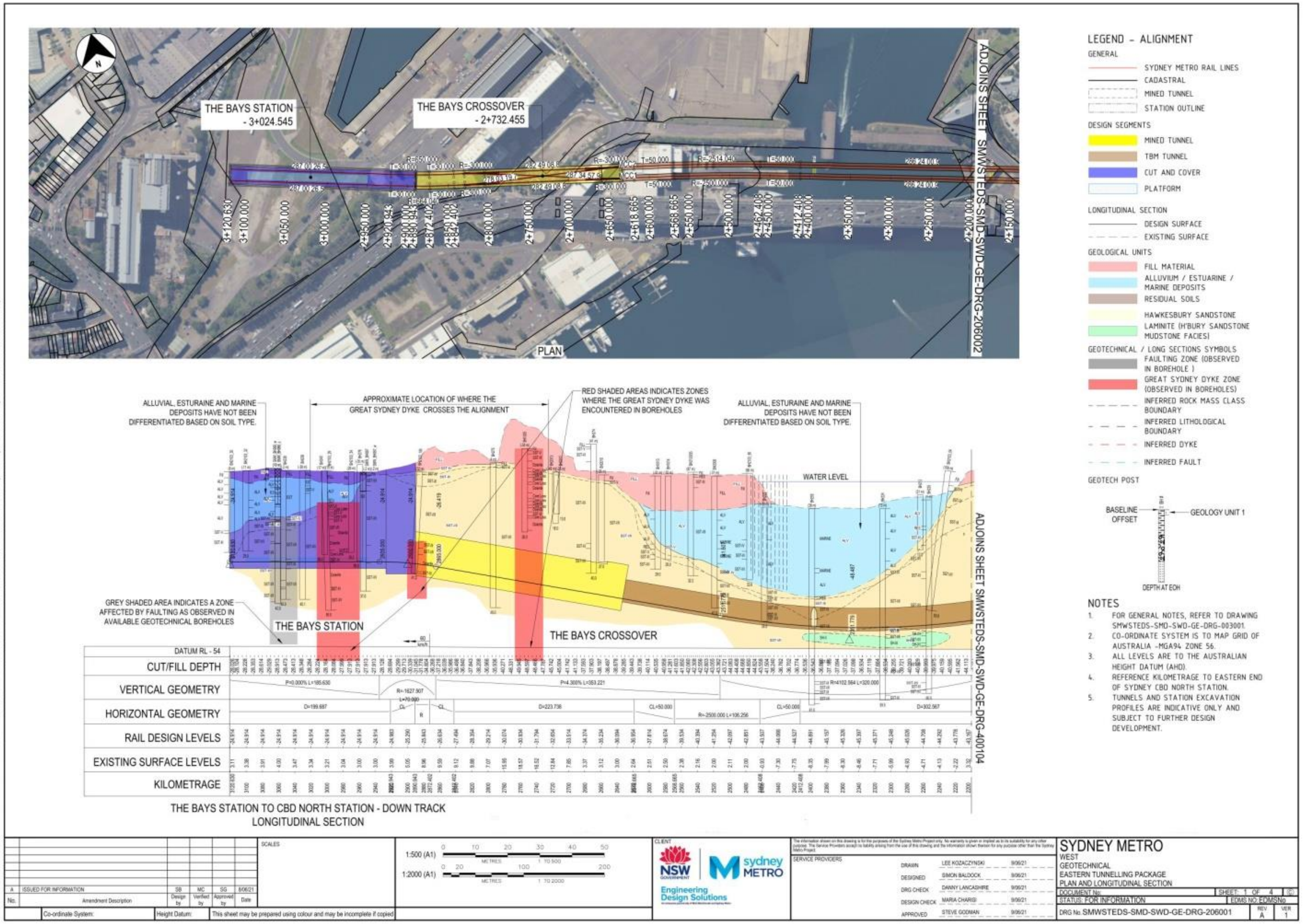
Qha: Quaternary alluvium (KH=3.6 – 1 m/day)

Rh: Hawkesbury Sandstone Class III/IV (HK=0.88 – 8E-02 m/day)

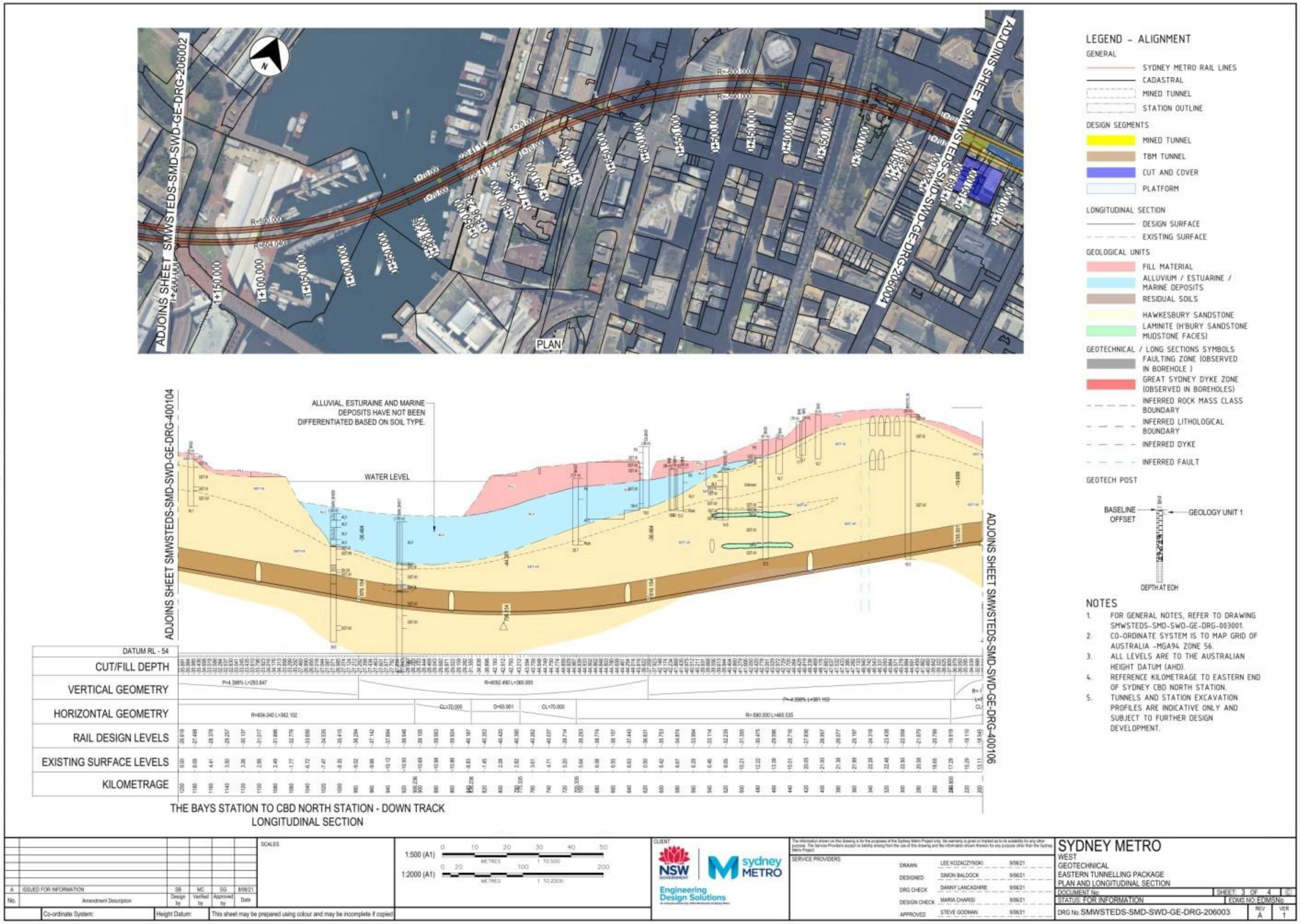
Rh: Hawkesbury Sandstone Class I/II (HK=0.6 - 8E-04 m/day)

Modelled groundwater table

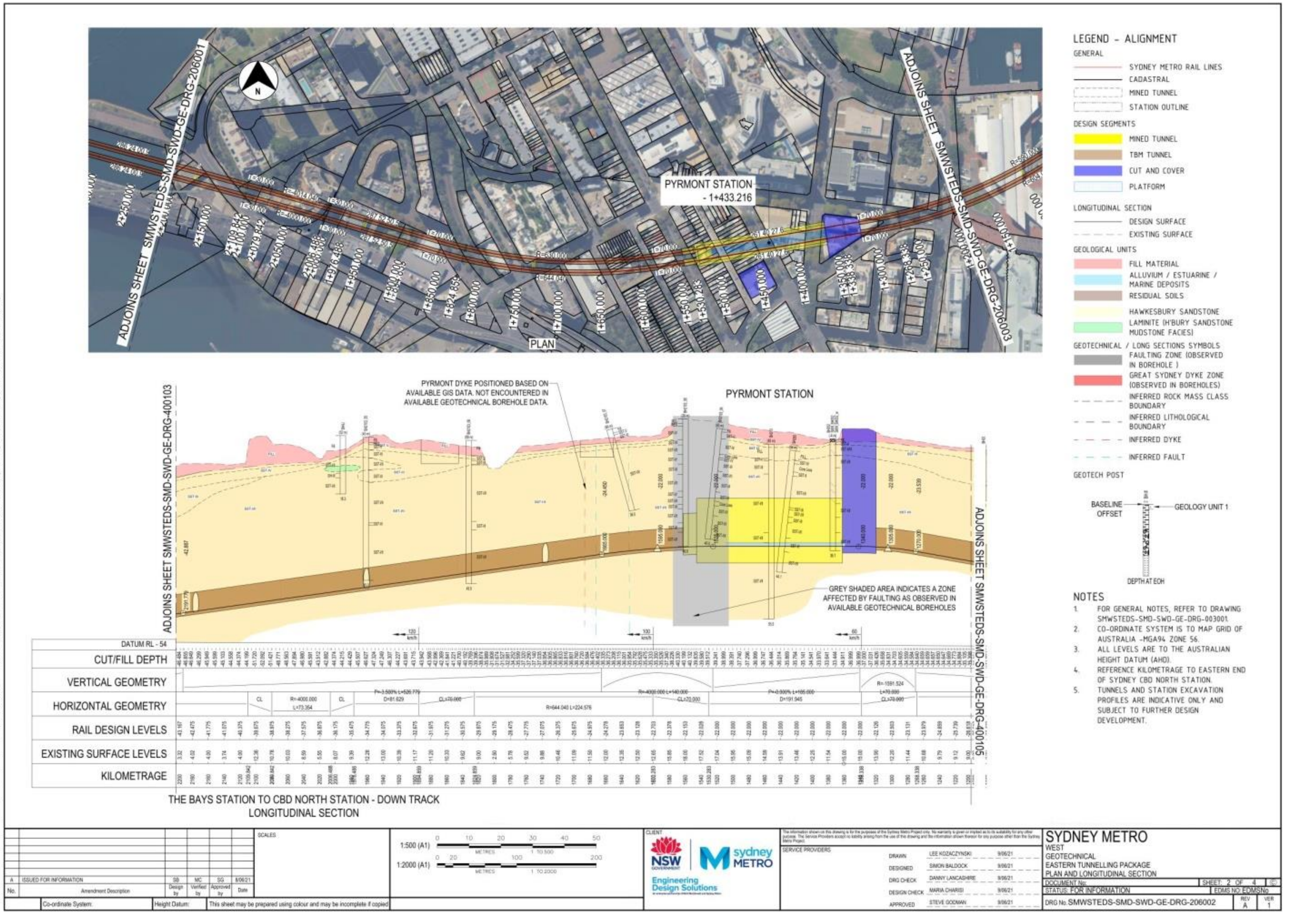
Appendix D: Geological Long Sections 1/4



Appendix E: Geological Long Sections 2/4



Appendix F: Geological Long Sections ¾



Appendix G: Geological Long Sections 4/4